



LIBRARY
UNIVERSITY OF
CALIFORNIA.

Fig. 1.

Sun.
Candle Flame.
Sodium.
Potassium.
Lithium.
Calcium.
Barium.
Strontium.

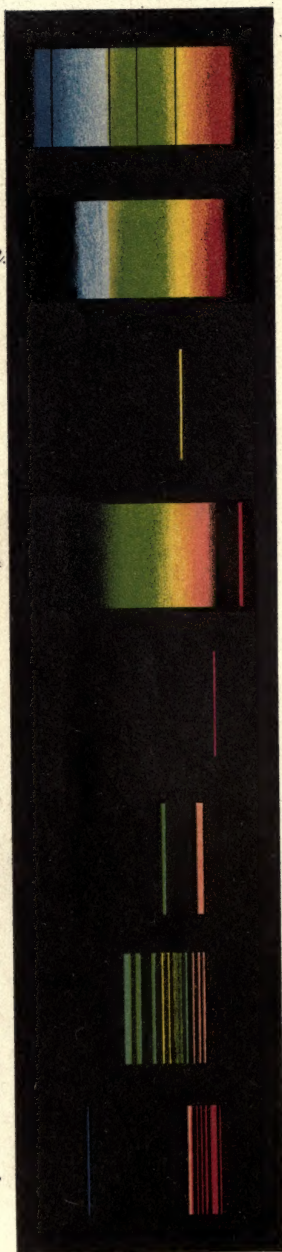


Fig. IV.

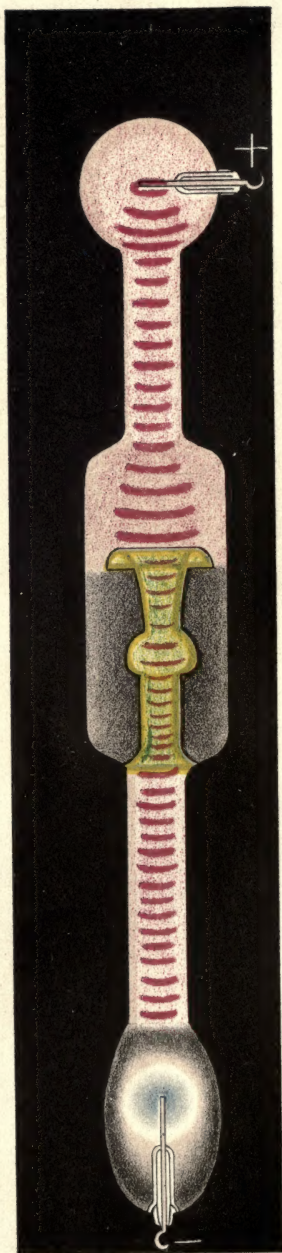


Fig. III.



Fig II.





INTRODUCTION TO EXPERIMENTAL PHYSICS

THEORETICAL AND PRACTICAL

INCLUDING

DIRECTIONS FOR CONSTRUCTING PHYSICAL APPARATUS
AND FOR MAKING EXPERIMENTS.

BY

ADOLF F. WEINHOLD,

PROFESSOR IN THE ROYAL TECHNICAL SCHOOL AT CHEMNITZ.

TRANSLATED AND EDITED, WITH THE AUTHOR'S SANCTION,

BY

BENJAMIN LOEWY, F.R.A.S.

FIRST SCIENCE MASTER AT THE INTERNATIONAL COLLEGE, SPRING GROVE, LONDON:
EXAMINER IN PHYSICS AT THE COLLEGE OF PRECEPTORS, LONDON.

WITH A PREFACE

BY

G. C. FOSTER, F.R.S. UNIVERSITY

PROFESSOR OF PHYSICS IN UNIVERSITY COLLEGE, LONDON.

LIBRARY
UNIVERSITY
CALIFORNIA

ILLUSTRATED BY 3 COLOURED PLATES AND 404 WOODCUTS.

LONDON:
LONGMANS, GREEN, AND CO.
1875.

0021
W 4

12190

PREFACE.

EVERYONE who has tried to teach elementary Physics must have become aware of the great difficulty which the subject presents to the majority of pupils. This difficulty is of a twofold kind, and arises partly from the nature of the facts with which the science deals, and partly from the nature of the reasoning, whereby the general laws of physics are established. A large proportion of the facts are such as either do not fall within common experience at all, or do so only under such complex conditions that their true nature is not easily recognised ; and moreover the kind of knowledge which is required in physics, is much more accurate and precise than that with which we are accustomed to be satisfied in relation to matters of ordinary life. Hence, in beginning the study of physics, we are obliged, not only to learn a large number of new facts, but also to adopt new habits of learning ; while we have, at the same time, to accustom ourselves to attach accurately defined meanings to the terms employed in discussing physical phenomena, and to reason about them with

mathematical strictness, and often by the help of technically mathematical methods. These characteristics of the study of physics give to it a value, as a means of training in habits of exact thinking, which probably no other study possesses in the same degree, but at the same time they make this study more than usually difficult, especially to beginners. The consequence is, that many students of elementary physics never succeed in gaining any really valuable acquaintance with the subject. They may retain general impressions of the results of some of the experiments they have witnessed, but they do not get exact conceptions which can cast light upon each other and grow within the mind; or they may possibly remember the words in which some of the general conclusions of the science can be stated, though without having any comprehension of what the real evidence for these conclusions is, or of the reasoning by which they are established: in short, what little is retained, in relation either to the experimental facts or to the laws of physics, is kept in mind by a pure effort of memory, in which the intelligence has no perceptible share.

It is probable that the frequency, with which results such as these attend the teaching of the fundamental parts of physics, has furnished one of the motives that have induced some authors and teachers to try to arrange this subject in a series of consecutive propositions set forth in a manner imitated from Euclid's Elements. It has, no doubt, been hoped that in this

way students would be forced to recognise the logical connexion between the different parts of the science. Practically, however, I believe that such a mode of teaching generally leads, at least in the case of beginners, to an aggravation of the evils it is intended to obviate. No doubt students who have acquired a little familiarity with geometrical reasoning easily recognise the logical sequence of the propositions, but very often they learn no physics; the whole matter is for them a rather uninteresting series of exercises on the geometrical principles they already know; while those to whom the geometry is a difficulty seldom get any benefit at all, either in the way of geometry or of physics. I am convinced that the true way to make the somewhat abstract notions necessarily encountered at the outset of the study of physics intelligible to beginners, is not to emphasise the abstractions, but to provide the learner with the clearest possible ideas of the concrete facts from which the abstractions are derived. In any sound system of teaching, particulars must come before generalities; for, unless a student has clear conceptions of individual phenomena, it is impossible for him to understand their mutual relations or the general conclusions that are based upon them. But although, in the abstract, the truth of these statements is not disputed by anyone, it is not always recognised as fully as it should be in the practical teaching of elementary physics. It is so obvious that the educational value of this subject depends essentially

on the mental discipline to be derived from mastering the reasoning processes by which the general conclusions of physics are established, and not on an acquaintance with particular physical facts, that teachers are tempted to forget how indispensable a preliminary knowledge of the facts is to the intelligent study of the reasoning.

The kind of knowledge, however, which is really serviceable for this purpose is not such as can be got by merely reading or hearing descriptions of phenomena, or even by seeing experiments made by a teacher: it needs that the student should observe and experiment for himself. It is not merely that the knowledge we obtain, by seeing and handling an object for ourselves, is more vivid and complete than what can be obtained second-hand through the testimony of others, but that a great part of the mental discipline which the study of physics is capable of affording, depends upon our becoming convinced, through direct personal observation, that the general laws of the science represent conclusions truly derived from an accurate examination and comparison of the impressions which the actual phenomena make upon our senses. It is, of course, neither needful nor possible to confine a student's attention exclusively to such matters as he can have personal experience of; as he advances in his studies he must necessarily depend upon books for the greater part of his knowledge; but, at the outset of his course, it is very desirable that as far as possible

his attention should be directed to things that he has seen and examined for himself; and unless he has learned by his own experience, at least in a few cases, what experimental evidence means, he will scarcely ever be able to appreciate rightly the evidence to be obtained by reading.

Another reason for introducing as much practical experimental work as possible into the elementary teaching of physics—which, though less fundamental than those already pointed out, is still of great practical importance—is the influence which it exerts upon the mental attitude of the learner. The great secret of effectual teaching in any subject is to excite the pupil's interest, so that, instead of being passively receptive, and regarding it as his teacher's business to make him learn, he may actively exert his mind in order to understand the matter in hand. In the case of physics no method is nearly so efficacious for this purpose as that of letting him make apparatus and try experiments with his own hands. The very slowness of the progress which this method makes unavoidable, and the length of time during which a single phenomenon and the conditions of its occurrence are necessarily kept before the mind, are, from an educational point of view, no slight advantages.

I need scarcely say that in thus laying stress upon the importance of a personal acquaintance with the concrete facts of physics, I have no intention of underrating the value of the mathematical discussion by which

alone the true import and mutual bearing of these facts can be discovered and expressed. The student who wishes to advance beyond the mere rudiments of the subject will inevitably find himself obliged to give at least as much attention to the mathematical as to the experimental side of it; but I think there can be little doubt that it is best for him to *begin* by studying separately experimental physics and pure mathematics, and not to encounter at first the combination of the difficulties of both subjects which the mathematical treatment of physics presents. If once he has acquired clear conceptions of the fundamental physical truths, and also the requisite familiarity with the methods of pure mathematics, he will find very little difficulty in bringing his mathematical knowledge to bear upon physical problems.

Hitherto, however, it has been very difficult for a teacher, even when thoroughly convinced of the importance of making the first instruction in physics as thoroughly practical as possible, to carry his views into practice; he has derived little or no assistance from the existing text-books of physics; and, unless he has been able not only to devise a general plan of instruction, but also to contrive every detail of the experimental work he gave his pupils to do, he has had no choice but to fall back upon the usual plan of reading a text-book, or at best of showing experiments with ready-made apparatus. But now all who wish to adopt a more satisfactory system have an excellent guide offered to

them in Professor A. Weinhold's *Vorschule der Experimental-Physik*, which has been translated by Mr. B. Loewy. This work constitutes a systematic treatise on elementary physics, founded upon a well-chosen series of experiments, which it is intended that the reader should perform with his own hands; and in order to facilitate the carrying out of this intention, very full instructions are given, both as to the precautions needed in making the experiments and as to the mode of constructing the necessary apparatus. These instructions are extremely clear and precise; and although to readers unaccustomed to experimental work they may sometimes seem needlessly minute, I feel sure that it will be found in actual trial that the apparently small matters to which attention is sometimes called are just such as make the difference between success and failure. With very few exceptions, anyone with a taste for mechanical occupations and a fair amount of handiness could, with patience and by carefully following the directions given, make all the apparatus referred to in the book.

Whenever this or some similar work comes to be commonly adopted in schools, physics will be in a fair way of becoming one of the most popular as well as most useful parts of school-work, instead of being, as it too often is now, less liked and worse taught than almost any other subject. But the conditions, under which alone such results can be expected, cannot be better stated than in the following extract from Professor

Weinhold's own Preface, with which I will bring my remarks to a close :—

‘The most indispensable qualification for anyone who wants to make real use of this book is *perseverance*. Skilfulness in practical operations, such as the working of metals or of glass, or in actually making experiments, is only to be attained through practice ; and since it is impossible for even the most careful written instructions to provide against every mistake that a student can possibly make, personal experience must every now and then be the real teacher. Whenever anything does not succeed the first time, the student should try it again ; but he should not try thoughtlessly, on the mere chance of better luck next time : he should endeavour by careful consideration to find out the cause of his ill success. The completion of a piece of apparatus, or the success of an experiment, well repays the trouble spent upon it ; the skill that has been gained in the process never turns out useless afterwards, and occasions arise on which even those whose chief occupations lie in quite other directions are able to recognise its value.’

G. C. FOSTER.

UNIVERSITY COLLEGE, LONDON :

December 1874.

CONTENTS.



GENERAL PROPERTIES OF MATTER.

ARTICLE	PAGE
1. Extension. Units. Determination of Volume	1
2. Impenetrability	7
3. Solid, Liquid, Gaseous bodies. State of Aggregation	10
4. Cohesion and Expansive Force	18
5. Porosity	29
6. Divisibility	32
7. Gravity. Absolute and Specific Weight	33

MECHANICS, OR THE EQUILIBRIUM OF BODIES (STATICS) AND THE MOTION OF BODIES (DYNAMICS).

8. Inertia	43
----------------------	----

1. *General Mechanics, and Mechanics of Solid Bodies.*

9. Force and Mass	48
10. Motion of Falling Bodies	58
11. Motion of Projectiles	65
12. Mechanical Work	72
13. Simple Machines	78
14. Equilibrium. Centre of Gravity. The Balance	103
15. The Pendulum	123
16. Centrifugal Force	131
17. Molecular Constitution of Solids. Rigidity. Elasticity	151
18. Adhesion	154

2. *Hydrostatics and Hydrodynamics, or the Equilibrium and Motion of Liquid Bodies.*

ARTICLE	PAGE
19. Surface of Liquids. Transmission of Pressure. Pressure in Vessels	158
20. Communicating vessels. Buoyancy. Principle of Archimedes.	179
21. Floating Bodies. Hydrometers	191
22. Fountains. Efflux from Orifices. The Screw-propeller . . .	196
23. Molecular Phenomena. Adhesion. Capillarity. Solubility. Diffusion. Endosmose	204

3. *Aërostatics and Aërodynamics, or the Equilibrium and Motion of Gaseous Bodies.*

24. Weight of Air. Loss of Weight in Air. The Balloon . . .	219
25. Atmospheric Pressure. The Barometer	228
26. Mariotte's Law	240
27. Applications of Atmospheric Pressure and of Mariotte's Law .	246
28. The Air-pump. Experiments with the Air-pump	270
29. The Suction-pump. The Forcing-pump	291
30. The Reaction of Efflux in Gases. Phenomena of Suction .	301
31. Molecular Phenomena in Gases. Condensation upon Surfaces. Absorption. Diffusion	316

ACOUSTICS.

32. Nature and Propagation of Sound	326
33. Number of Vibrations. The Siren. Pitch	344
34. Vibrations of Strings. Overtones. Resonance. Timbre . .	355
35. Vibration of Plates, Bells, Rods, and Air in Tubes . . .	368
36. The Organ of Voice. Vowel Sounds. Flame-Manometer . .	390
37. Beats. Concord. Discord	404

OPTICS.

38. Propagation of Light. Shadow. Photometers	409
39. Reflection of Light. Mirrors	427
40. Refraction of Light. Prisms. Lenses	454
41. Dispersion of Light. The Spectrum	480
42. The Eye. Vision. Optical Instruments	514
43. Binocular Vision. The Stereoscope. Various Visual Effects .	533

ELECTRICITY AND MAGNETISM.

1. *Frictional Electricity.*

ARTICLE	PAGE
44. Electrical Attraction and Repulsion. Conductors and Non-conductors	551
45. Induction. The Electroscope. The Electrophorus	562
46. Distribution of Electricity upon Conductors. Electrical Machine	584
47. Condensers of Electricity. Effects of Electrical Discharge	611

2. *Contact-Electricity.*

48. Contact-Electricity. Galvanic Element. Galvanic Current	647
49. Effects of the Galvanic Current upon Conductors	668
50. Action of Galvanic Currents upon each other. Ampère's laws	693

3. *Electro-magnetism. Magnetism. Induction by Currents.*

51. Electro-magnetism	700
52. Magnetism	735
53. Induction of Currents	748

HEAT.

54. Expansion by Heat. The Thermometer	756
55. Melting and Freezing	786
56. Evaporation, Ebullition, and Condensation of Vapour	792
57. Transmission of Heat. Radiation. Conduction	809
58. Specific and Latent Heat	816
59. Means of raising and lowering the temperature of bodies	826

INDEX	841
-----------------	-----

LIST OF TOOLS, ETC.	849
-----------------------------	-----

Errata.

- Page 547, first line, *for* Phenakistokope *read* Phenakistoskope.
„ 621, last line, *for* stoll-balls *read* stool-balls.
„ 654, Fig. 336 is *inverted*.

LIBRARY
UNIVERSITY OF
CALIFORNIA.

GENERAL PROPERTIES OF BODIES.

1. *Extension. Units. Determination of Volume.*—

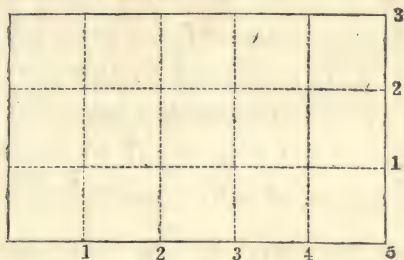
When we examine the various bodies which surround us, we find that, notwithstanding the many differences which they exhibit, there are some properties which are common to all of them. The most obvious of these general properties is extension in space. In most bodies this property is perceived at once: a book, a block of wood, and thousands of other objects possess length, breadth, and thickness; and these dimensions of a body in three different directions constitute together its extension in space. In some cases, instead of speaking of the breadth of an object, we speak of its width; or of its depth, rather than of its thickness; but there are always three different dimensions, although it may sometimes appear at first sight that a body has only one or two dimensions. A sheet of tissue paper, or, better still, of gold leaf, has a very appreciable length and breadth; but its thickness is so small that special instruments are required to measure and even to perceive it. But several hundred small sheets of tissue paper placed one upon another and slightly compressed, or a large sheet repeatedly folded, would form a layer of measurable thickness: about 500 sheets of moderately fine tissue-paper are required

to form a layer one centimetre in thickness. About 10,000 leaves of the finest gold leaf piled one upon another would have together a thickness of only one millimetre; yet each one of these leaves possesses a definite although extremely small thickness. A thread wound from the cocoon of a silkworm is so fine that only its length is appreciable by the naked eye; still it has a certain breadth and thickness ($\frac{1}{100}$ th of a millimetre), as may be seen with the help of a magnifying glass.

In physical experiments the metre and its subdivisions are frequently used for measuring dimensions. The metre is very nearly the $\frac{1}{40,000,000}$ th part of a meridian; that is, of a circle supposed to be drawn on the surface of the earth through both poles. The metre is divided into 10 decimetres, into 100 centimetres, and into 1,000 millimetres ($1^m = 10^{\text{decim}} = 100^{\text{cm}} = 1,000^{\text{mm}}$). In order to be able to compare the magnitude of surfaces and the volumes of bodies, square and cubic measures are required. In measuring a length we ask, how many times it contains a certain other length, called the unit of length; and according to the magnitude of the length to be measured we choose as our unit the metre, decimetre, centimetre, or millimetre. Likewise, in measuring a surface, we have to ascertain how many times it contains another definite surface, which represents the unit of superficial measurement. This unit is always a square; that is, a plane rectangular and equilateral surface of which each side is equal to the unit of length. We have therefore square metres, square decimetres, etc.

The magnitude of a superficial area can, however, only be found indirectly, by a calculation, from the measure-

ment of the dimensions of the surface. If the surface is rectangular (fig. 1), its area in square units is the product of the linear units in its length and breadth. Thus, if the figure has a length of 5 centimetres, and a breadth of 3^{cm}, it can be actually cut up into 15 squares, each

FIG. 1 (*real size*).

having an area of one square centimetre, and its superficial area will evidently be $3 \times 5 = 15$ square centimetres. A parallelogram which is not rectangular, $abcd$ (fig. 2), can be converted into a rectangle by cutting off a triangle abe at one end, and putting it on at the other. The parallelogram $abcd$ has, therefore, an equal area with the rectangle $ebcf$, and its magnitude is found by

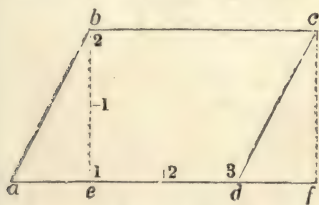
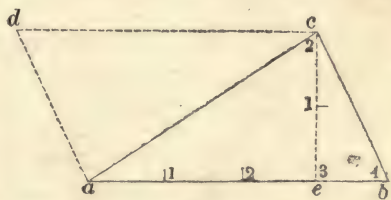
FIG. 2 (*real size*).

FIG. 3.

multiplying one of two opposite parallel sides, ad or bc , into their perpendicular distance eb ; $abcd$ (fig. 2) has an area of $2 \times 3 = 6$ square centimetres.

A triangle may be considered as half a parallelogram; abc (fig. 3) is half of $abcd$. The area of the triangle

is thus seen to be half the product of one of its sides, $a b$, into the perpendicular distance, $e c$, of the opposite vertex. The area of $a b c$ (fig. 3) is $\frac{2 \times 4}{2} = 4$ square centimetres.

The area of a circle is found by multiplying its radius, that is, the distance of the centre from the circumference, once by itself and by the number 3.1416. This number, which expresses the length of the circumference, if the diameter is equal to 1, is frequently denoted by the symbol π ; its value is more precisely 3.1415926, or approximately $\frac{22}{7}$. The area of a circle of 6^{cm} diameter, or 3^{cm} radius, is $3 \times 3 \times 3.1416 = 28.2744$ square centimetres.

The unit for the measurement of the solid contents or volumes of bodies is a cube, that is, a space bounded

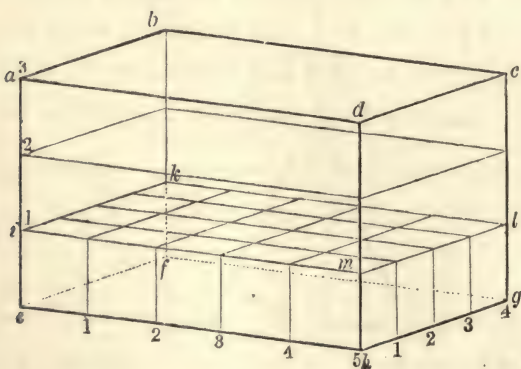


FIG. 4 (real size).

by six equilateral rectangular faces, each equal to the unit of surface, and each of whose edges is equal to the unit of length. Thus we have cubic metres, cubic decimetres, etc. The cubic centimetre especially is of

frequent use in physical works, and is written briefly thus 'cc.'

The volume of a rectangular solid like $abcde fgh$ (fig. 4)¹ is easily ascertained; for we may suppose the solid to be cut into flat plates each one unit in thickness; each of these plates, as $iklmefgh$, may be divided into cubic centimetres, and we shall obtain 20^{cc} from a plate 5^{cm} in length and 4^{cm} in breadth; and the number of such plates will be equal to the number of linear units in the thickness of the body. In the present case there are three such plates, each of 20^{cc} . The entire volume of the body is, therefore, $3 \times 4 \times 5 = 60^{\text{cc}}$. The volume of a rectangular solid is thus the product of its length,

¹ Many figures in the text, intended to show all three dimensions of the objects represented, are drawn in what is called anisometric parallel projection; such figures are marked '*an. proj.*' The scale on which the

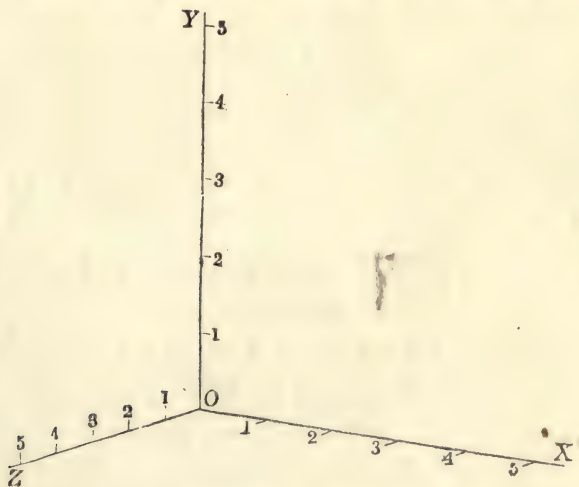


FIG. 5 (*an. proj. real size*).

figures marked 'real size' are drawn will become clear from fig. 5. All dimensions in height, o Y, are represented in their real magnitude; the dimensions from left to right o X, are $\frac{9}{10}$ th; those from the front to the back of the figure o Z, are $\frac{1}{2}$ of the true magnitude.

breadth, and depth in linear units. The same principle applies to solids whose cross-section does not vary. In such solids (figs. 6 and 7) the perpendicular distance of two opposite equal sides is to be taken as the length. Thus the volume of the solid represented in fig. 6 is $\frac{3 \times 2}{2} \times 4 = 12^{\text{cc}}$; that of fig. 7 is $2 \times 2 \times 3.1416 \times 5 = 62.832$. (The abbreviations cc., m., c., etc., are written at the top, between the integer and the decimal fraction ;

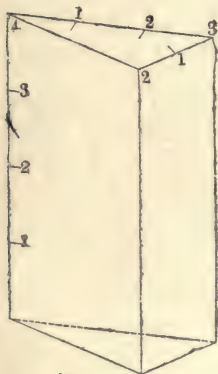


FIG. 6 (*an. proj. real size*).

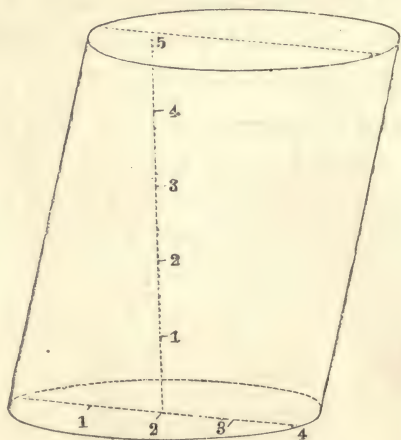


FIG. 7 (*an. proj. real size*).

read : sixty-two, and eight-hundred and thirty-two thousandths cubic centimetres).

The volume of a sphere is found by multiplying the diameter twice by itself, and by 3.1416, and dividing the product by 6. Thus the volume of a sphere of 10^{cm} diameter is $\frac{10 \times 10 \times 10 \times 3.1416}{6} = 523.6$. The cor-

responding units for the measurements of lengths, areas, and volumes clearly bear different proportions to each other. Thus the square metre is a rectangle of 100^{cm}

in length, and 100^{cm} in breadth: hence, while the linear metre contains 100 linear centimetres; the square metre contains $100 \times 100 = 10,000$ square centimetres. Similarly, a cubic decimetre is a cube of 10^{cm} in length breadth, and thickness; it contains, therefore, $10 \times 10 \times 10 = 1000^{\text{cc}}$. The following table exhibits the relative proportions of the subdivisions for the various kinds of units—

Measures of Length.

Metre	Decimetre	Centimetre	Millimetre
1	10	100	1000
	1	10	100
		1	10

Measures of Area.

Square Metre	Square Decimetre	Square Centimetre	Square Millimetre
1	100	10,000	1,000,000
	1	100	10,000
		1	100

Measures of Volume.

Cubic Metre	Cubic Decimetre	Cubic Centimetre	Cubic Millimetre
1	1000	1,000,000	1,000,000,000
	1	1000	1,000,000
		1	1000

The cubic decimetre when used for the measurement of liquid bodies is called *litre*. A litre is thus equal to 1000^{cc} .

2. *Impenetrability*.—The sense of touch informs us of another important property of bodies. If we attempt to penetrate into the space occupied by a body, for instance, by a piece of wood or stone, we either find it altogether impossible, or, as in the case of a lump of clay or water contained in a vessel, we only succeed in placing our hand into the space occupied by the clay or the water, by actually pushing aside the substance,

these bodies. From this it appears that the substance or matter, of which bodies consist, fills space in such a manner that no other body can at the same time occupy the same portion of space. This property of matter is called impenetrability. It is common to all kinds of matter, even to air, although it is not so apparent in this body as in others, because air is invisible, and may be displaced without sensible effort. But if a



FIG. 8 ($\frac{1}{8}$ real size).

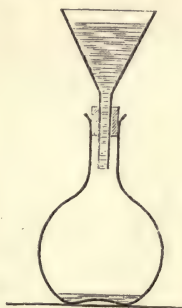


FIG. 9 ($\frac{1}{8}$ real size).

tumbler, which in the usual meaning of the word is empty, be inserted mouth downwards, as shown in fig. 8, into a jar containing water, the water will not enter the tumbler, because the air which filled it previously cannot escape. We observe, on the contrary, that the water in the larger vessel gives way before the air which is compressed in the tumbler, and rises in the jar, or runs over if the jar was full at first. When we fill a bottle with water, the air usually escapes freely; but if a funnel with a narrow tube be fitted air-tight into the bottle by means of a perforated cork (fig. 9), it will be impossible to fill the bottle because the air cannot escape. It will, however, be found in this and in the last experiment, that a small quantity of water will enter the tumbler or the bottle ;

but this happens because air, as will be shown further on, is a very compressible body, and its volume is slightly diminished in these experiments by the pressure exerted by the water in the jar, and in the funnel respectively.

Corks suitable for such experiments must be selected with care from a corkcutter's stock. They should be close grained, free from holes, and rather soft. A cork intended for a particular orifice should always be of somewhat greater width than the hole itself; by gentle hammering, or by rolling it between a small board and

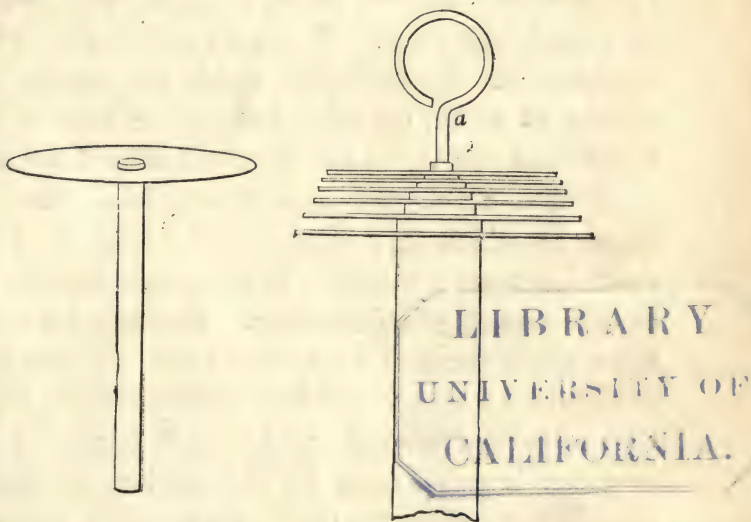


FIG. 10 ($\frac{2}{3}$ real size).

the table, it may be softened so as to fit tightly into the neck of a glass vessel without breaking it. A cork of suitable size, if not readily found, may be cut from a larger one with a very sharp knife, which is moved like a saw, or it may first be cut roughly, and then shaped by filing with a flat file. Holes in corks are best made by means of proper *cork-borers* (fig. 10). These are tubes of thin brass, open at both ends, provided with a handle at one extremity, and sharpened at the other; a set usually contains 6 or 10, varying in width from 3 to 15mm. In penetrating through the cork the tube is turned with a slight pressure, and the plug

which remains in the borer is then removed by the small brass rod *a* (fig. 10). Blunt borers may be sharpened by applying a flat file outside and a round one inside the edge. Such a round file, called a 'rat-tail,' is also often useful for making the holes smoother, or it may serve for widening a hole, which has been simply made with the bradawl, to the required size. The tubes which are to be passed through the cork should be greased or oiled, and the hole should be just so wide as to allow the tube to be pushed in without the risk of breaking.

3. *Solid, Liquid, Gaseous Bodies. State of Aggregation.*—Many bodies (such as wood, iron, stone, etc.) have a definite form or shape, which can only be altered by considerable force. These are called *solid*, or better *rigid* bodies. Those bodies which are usually called liquids, as water, oil, etc., change their form if transferred from one vessel into another; they have not an unalterable form, but immediately take that of the vessel in which they happen to be placed. Liquids show, however, a tendency to assume a definite form, namely that of globular drops. This may be observed when small portions of a liquid are allowed to run slowly from a vessel, or, better still, when one liquid is kept suspended in another. Olive-oil is not so heavy as water, it swims upon it; and alcohol, or spirits of wine, is still lighter than oil. Alcohol and water may be mixed, while oil does not mix with either. A mixture of alcohol and water may then be made which is exactly as heavy as the oil, and in which the latter neither sinks nor rises to the surface. A small quantity of oil is placed upon water by means of a thin rod of glass or wood, and, while the liquid is frequently stirred, alcohol is added until it is found that the small globules of oil neither sink nor rise. About equal quantities of water and alcohol are required for

this purpose. It is not easy to produce a mixture which is exactly as heavy as the oil. The lower portions usually contain more water, and are heavier; while the upper layers contain more alcohol, and remain lighter; the oil, therefore, seeks the middle of the mixture. The lower end of a small pipette (fig. 11) is now inserted into oil, and the pipette is nearly filled by



FIG. 11 ($\frac{2}{5}$ real size).

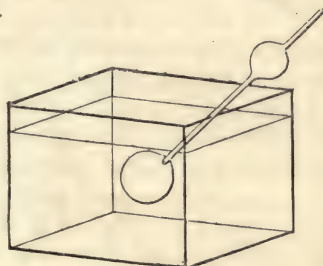


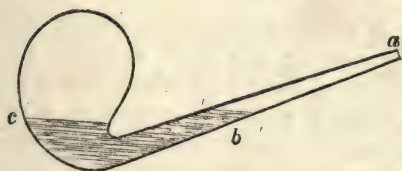
FIG. 12 ($\frac{1}{5}$ real size).

sucking at the upper end, which is then closed by the finger. The point of the pipette is then immersed to about the middle of the mixture, the upper end opened, and the oil allowed to escape (fig. 12). By repeatedly filling the pipette, and emptying it into the oil already in the mixture, globules of more than 3^{cm} in diameter may be produced. If the liquid be gently stirred, the oil-drop will become distorted, and assume various shapes, but it always returns to the spherical form if allowed to come to rest. Rapid stirring tears the ori-

ginal globe asunder, and each separate portion forms an independent sphere.

It is very desirable to perform this and other similar experiments in glass vessels with flat sides, because objects appear distorted if seen through the sides of glass vessels which are curved: they would only present a correct appearance by looking at them from above. Such vessels with flat rectangular sides are rather expensive, but may be procured by removing the neck from the square bottles in which foreign liqueurs are sometimes imported. A piece of ignited charcoal, or of pastille, held in contact with glass immediately in front of a crack, will serve to extend it in any desired direction, so as to cut off a neck or rim, etc. A useful pastille may be made in the following manner: 25^{cc} alcohol, or about 20 grammes (see article 7), are poured over 4 grammes gum benzoin, and an equal weight of solid storax, in a small glass, and allowed to stand for a day, during which it is repeatedly shaken. A solution is also made of 20 grammes gum arabic and 8 grammes gum tragacanth in 120^{cc} water (120 grammes). This is boiled in a small tin pot, with continual stirring and occasional addition of water to replace that which has boiled away, until the whole is dissolved. Both solutions, with any sediment, are then transferred to a mortar and well rubbed together with about 70 or 80 grammes powdered wood charcoal, until the mass is sufficiently thick to be rolled on a board into quill-shaped sticks, from 10 to 15^{cm} long, and from 6 to 8^{mm} in thickness, which are exposed for a day or two to the air to dry. Such a stick, when lighted in the flame of a candle, may be kept alight by gently blowing on it occasionally. It must be kept in close contact with the glass but without pressure, and from time to time turned so as to prevent it from burning on one side only. The first crack at the edge of a piece of glass, or at the neck of a bottle, is obtained by making a scratch in the glass with a triangular file, and heating it with charcoal or pastille until a crack is formed. This requires sometimes strong blowing and some patience, but is safer than heating the glass and bringing a drop of water upon the heated place, which often produces several irregular cracks. It will be well to practise the operation first on a piece of common glass before undertaking it with the vessel intended for the apparatus. The pastille is best extinguished by pushing the lighted end 3 or 4^{cm} deep into dry sand, or into the end of a glass tube large enough to admit it easily, it will then be ready for use, and easily lighted when again required. The sharp edges along the crack should be rounded off upon a common grindstone which is turned slowly.

Liquid and gaseous bodies are both termed *Fluids*, but the latter class is not capable of forming drops like the former. If placed in a vessel which is not closed they escape into space. The mass of air which surrounds the earth to a height of many miles is called the *atmosphere*, and common air is hence often called atmospheric air. Bodies like air have neither a definite form nor a definite volume. The smoke which issues from a chimney, or from a cigar, is seen to spread out and to increase its volume continually, until, in consequence of this expansion, it becomes too rarefied to be discerned by the eye. This smoke is a body like air, rendered visible by an admixture of fine soot and other particles which are carried up by the ascending gas. The alteration in volume may be easily observed also in pure atmospheric air. A glass retort, such as is used for physical and chemical purposes, is partly filled with water and inverted (fig. 13). By sucking at the

FIG. 13 ($\frac{1}{6}$ real size).FIG. 14 ($\frac{1}{6}$ real size).

aperture *a* the water rises at *b* and sinks at *c* : *the air above c expands*. But by firmly closing the lips round

the aperture and strongly blowing into it, the water will be made to sink at *b* and to rise at *c*: *the air above c is compressed*. If the neck of the retort be held first very slightly inclined and filled with water up to *a*, and then turned so as to become nearly or quite vertical, the water will immediately sink a little below *a*, because the weight of the water in the neck, which now forms a higher column than before, compresses the air above *c*. The pressure of the hand can also be made to show the compressibility of air. A medicine bottle is closed by a well-fitting cork; one end of a piece of glass tube is passed through the cork, the other end into a small bladder (a calf's bladder), which is firmly tied round it. Holding the bladder by the cork, it is filled with water and the bottle then placed upon it in an inverted position (fig. 14). If the bladder be now strongly pressed, some of the water will pass into the bottle, as far as *a*; but if the pressure ceases, the air within the bottle, which has been compressed, expands again, and drives the water back into the bladder. The bladder when wet slips easily off the tube; this may be prevented by passing the latter through a cork, and tying the bladder firmly round the cork.

If a piece of glass tubing is required for any purpose, it may be cut from a longer tube by making a scratch across it with a triangular file, or a knife-blade of hard steel which has a rough edge. To sharpen such a blade it should be ground on a coarse stone without water. Tubes of less than 1^{cm} in diameter require only a single scratch across one side, and may be broken off by a conjoint sharp pull and bend, placing both thumbs upon the tube opposite to the scratch. Stronger tubes must be filed all round and cracked along the scratch by charcoal or pastille. The sharp edges at the fracture must be rounded off, especially in tubes which have to be inserted into corks. In smaller tubes the edges disappear if the end is simply heated to redness; but in thick and

wide tubes they must be smoothed on a grindstone. For heating, a spirit lamp is used, or coal gas where it is accessible. Two kinds of spirit lamps are mostly in use: the simple spirit lamp (fig. 15)

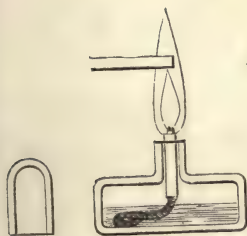


FIG. 15 ($\frac{1}{5}$ real size).

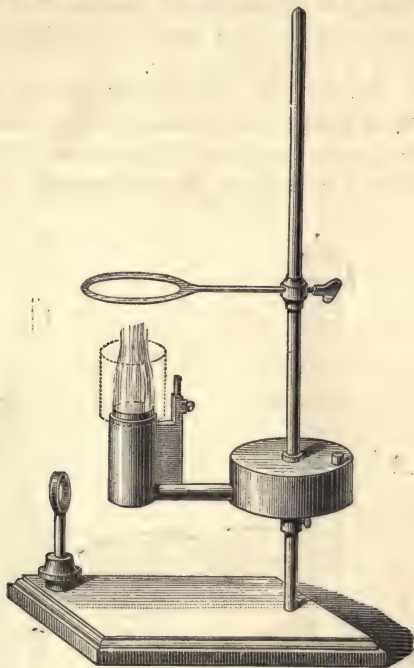


FIG. 16 ($\frac{1}{5}$ real size).

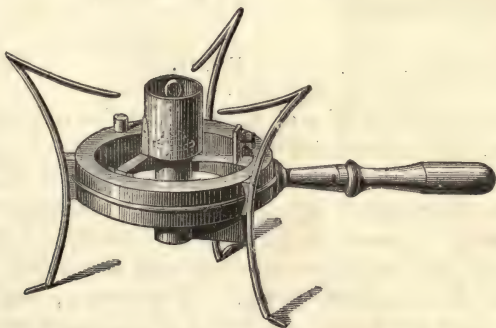
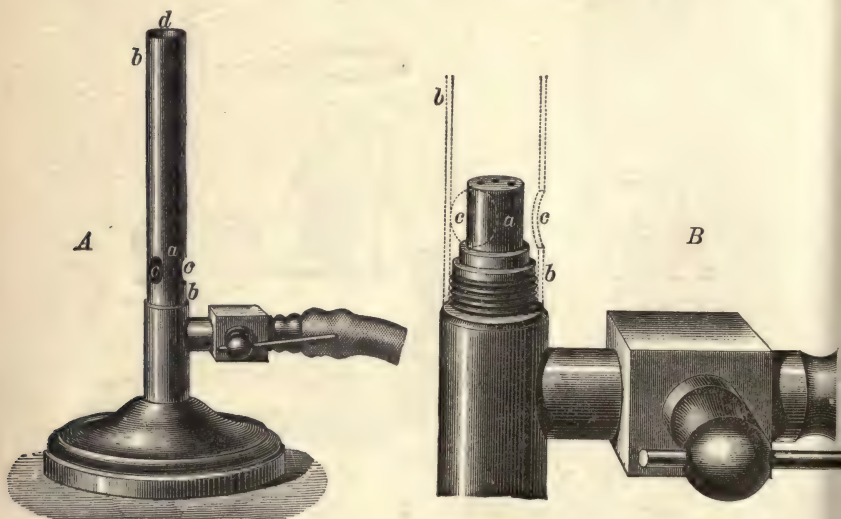


FIG. 17 ($\frac{1}{5}$ real size).

serves for smaller objects, or for moderate heating. For producing very high degrees of heat a Berzelius's Argand spirit lamp is required, two varieties of which are shown in figs. 16 and 17.

In one variety the spirit holder is separated from the burner, in the other it surrounds it. The burner, when not in use, must be covered by a cap, otherwise the alcohol evaporates, while water collects in the wick, and renders it difficult to light it again. The ground-glass caps crack very easily, and may be replaced by loosely fitting brass caps.

The flame of common coal gas deposits soot on objects held into it. A special contrivance, called a *Bunsen's burner* (figs. 18 and 19), is therefore required if gas is used for heating purposes. It consists of a common jet with several fine holes *a* (fig. 18, *B*), which



($\frac{1}{2}$ real size).

FIG. 18.

($\frac{5}{4}$ real size).

is surrounded by a tube of metal *b b*, at the bottom of which are openings for the admission of air, *c c*. The gas which issues from the jet becomes thus mixed with air, and burns at *d* with a non-luminous flame, which is without smoke, resembling the flame of a spirit lamp, but much hotter. The gas is supplied through a short horizontal tube, which is connected with a gas pipe by means of a piece of India-rubber tubing. If necessary, the tube may be slipped over a common burner in the manner shown in fig. 20, which prevents the tube from forming a sharp bend. It is convenient to have a stopcock attached to the horizontal tube. The gas should only burn at *d*, but never within the tube, at *a*. If the flame cannot be reduced without receding into the tube, the

air-holes *c* are too large; but if they are too small, the flame is yellow and not blue. For regulating the size of the air-holes a moveable ring, fig. 19 *c*, is used; it has corresponding holes to those in the tube, which in different positions may be used either for fully admitting or for partially shutting off the air.

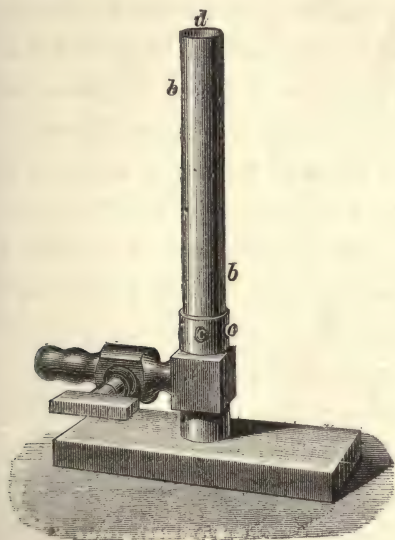


FIG. 19 ($\frac{2}{3}$ real size).

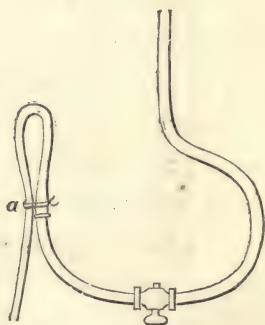


FIG. 20 ($\frac{1}{8}$ real size).

There are many bodies like atmospheric air, which are called *gases*. Such bodies are therefore distinguished as *gaseous* or *aëriform* bodies.

Numerous bodies are capable of assuming each of the three different states which have been considered. Thus water, which ordinarily is a liquid, becomes ice, a solid, in the cold, and steam, a gas, if sufficiently heated. These three states, in which bodies occur, are called their *states of aggregation*. The distinguishing characters of these states are briefly:—

SOLID bodies.—*Definite* Shape. *Definite* Volume.

LIQUID bodies.—*Indefinite* Shape. *Definite* Volume.

GASEOUS bodies.—*Indefinite* Shape. *Indefinite* Volume.

4. *Cohesion and Expansive Force*.—The particles of a solid can be separated only by force. They are maintained in their natural position by the force of *Cohesion*. But in gaseous bodies not only is no force required to separate their particles, but, on the contrary, it is only by force that their separation can be prevented. This property, the *Expansive Force* of gases, is indicated by the expansion of smoke in air, but it is more distinctly observable when gases are allowed to enter a vacuum space, that is, a space from which the air has been removed. Many gases are not colourless and invisible like air, but are coloured and hence visible; they are therefore well adapted for these experiments. But these gases are mostly poisonous and not easily prepared; those not well acquainted with the chemical management of such gases should therefore use smoke for the present purpose.

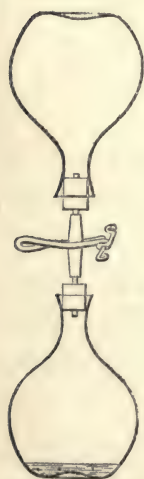


FIG. 21
($\frac{1}{4}$ real size).

Two small glass flasks of equal size are provided with well-fitting corks; a short glass tube passes through each cork. The projecting ends of the tubes are connected by a piece of india-rubber tubing, which can be closed by a pinch-cock, fig. 21. To remove the air from one of the flasks a layer of water, 6 or 8^{mm} high, is introduced into it, and the flask tightly closed by its cork, which remains connected with the cork of the second flask, this being in the meantime placed aside. The pinch-cock being opened, the water in the flask is boiled over the spirit-lamp until a strong jet of steam issues from

the tube, and the space in the flask has become quite clear, indicating that it is now filled by pure steam and not by particles of water mixed with air. The pinch-cock is then closed and the flask immediately removed from the lamp, or the pressure of the steam inside might burst it. The air in the flask has been displaced by steam, and after cooling, which may be hastened by placing the flask in cold water, the steam is reconverted into water, leaving in the flask a space which, though not a perfect vacuum, is sufficiently near it for the present experiment. The second flask is now filled with smoke by inserting through its neck, to about the middle of the flask, a wire to which a piece of ignited fusee is attached. As soon as the bottle is filled with dense smoke, the wire and fusee is withdrawn and the flask set upon its cork. On opening the pinch-cock the mixture of air and smoke immediately enters the vacuous flask, and as the air now fills a larger volume, it is more rarefied than previously; this is shown by the clearer appearance of the smoke. If the flask which contains the smoke is not connected with the vacuous space, but simply left to stand open, the smoke would also have expanded, though much more slowly, because the surrounding air retards the expansion.

It can be ascertained whether the apparatus is air-tight by immersing the flask in water, so that the cork is covered, when on blowing strongly through the tube small air-bubbles will rise from every leak. Should the projecting piece of glass tube be too short for this operation, a longer india-rubber tube may be temporarily attached. The tubing generally used for connecting the various portions of apparatus consists mostly of vulcanised india-rubber, or caoutchouc which has been made more soft and elastic by an admixture of sulphur. Such tubing is of a grey colour; another

kind, from which the sulphur has been again removed, is black. The grey tubing which is sold differs much in quality. Only good tubing should be used in physical experiments; although more expensive, it lasts much longer than that of inferior quality. It should be very elastic, so as to be capable of being stretched to thrice its original length without showing the smallest cracks, and should pass conveniently over a glass tube of its own external diameter; when cut, the surface of the section should be perfectly smooth and bright. The quality of the black tubing is not so variable, but it sticks inconveniently to glass surfaces, and its use is therefore restricted. A good rubber tube should fit air-tight upon a glass tube of the proper size without being tied.

The pinch-cocks used for closing india-rubber tubes are spring-clamps of brass, fig. 22, *A* and *B*. The form shown at *A* may be easily made with the help of a pair of flat and round pliers, figs. 23 and 24. A brass wire about 30^{cm} long, and 25^{mm} thick, is

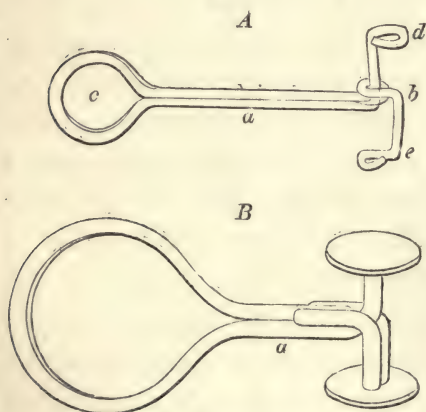


FIG. 22 (*A* $\frac{1}{2}$ real size, *B* real size).



FIG. 23
($\frac{2}{3}$ real size).



FIG. 24
($\frac{2}{3}$ real size).

bent into a ring *c*, with two parallel projections *a*. One of these, the lower in the figure, is bent at right angles, and a small ring *d* is made at the end; the other projecting arm, the upper one in the figure, is bent round the upright portion of the former into an ear *b*, then also at right angles, and finally turned at its extremity into the small ring *e*. To produce the required elasticity the ring *c* must be flattened by the hammer.

Brass and copper possess the property of becoming soft and flexible if exposed to a red heat; but they regain their hardness

and elasticity by hammering. Bright commercial brass wire is not so soft as brass which has been thoroughly heated; but it is still somewhat flexible. The ring may be flattened by a good smooth hammer upon an even hard surface, or best upon a small anvil. A ring thus hammered equally all round opens slightly; to keep the two arms *a* close together, the hammer should be held in a somewhat slanting direction, so as to make the external edge of the ring thinner than the interior.

On applying pressure at the ends *d* and *e* by thumb and forefinger, the bars *a* separate, and the rubber tube is inserted between them; if the pressure ceases, the bars approach each other and close the tube.

If not carefully examined, liquid bodies manifest neither the cohesion of rigid bodies, nor the expansive force of gases. Poured from a vessel, a liquid breaks up into single drops; on immersing the hand in water very little resistance is felt. Closer observation proves, however, that cohesion exists between liquid particles, although it is small. Without cohesion water poured from a vessel would not form drops, but extremely fine particles like dust. A small dry needle placed horizontally upon water will not sink, because its small weight is not sufficient to overcome the cohesion of the liquid particles at the surface, and to break through them. But if the point is immersed, the needle immediately sinks; this proves that the needle was not swimming upon the water, but was prevented from sinking by the cohesion between the liquid particles.

The cohesion of liquids is most obviously manifested by the liquid pellicles or films which may be formed from all liquid bodies, but most easily from a solution of soap in water. These liquid films demonstrate not only a comparatively strong cohesion, but also a distinct tendency of the particles to contract and thus to occupy

the smallest possible area. Some experiments on liquid films are exceedingly beautiful. A wire ring with a handle is immersed in soap solution contained in a flat saucer, and then withdrawn. A thin even film will be



FIG. 25 ($\frac{3}{4}$ real size).

formed within the ring. If this film be gently blown upon, it will become curved, and finally form a little bag, fig. 25, which contracts again if the blowing ceases, and assumes its former appearance of a plane circular surface. But if the handle of the ring, while the blowing continues, be turned between the fingers, the bag will appear to become tied up, will separate itself from the ring and immediately form a beautiful round soap-bubble. If a very fine silk thread, wound from a cocoon, is tied to two points of the ring, *a* and *b*, fig. 26, *A*, *B*, and the film which is

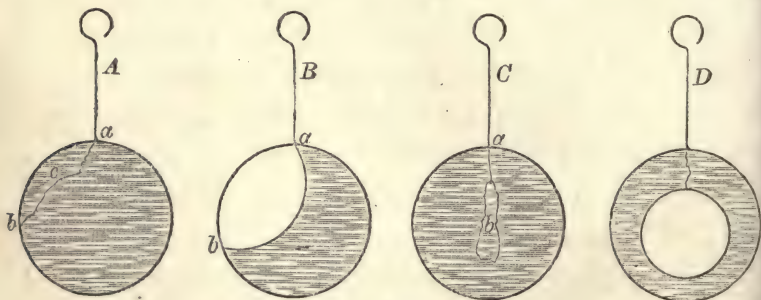


FIG. 26 ($\frac{1}{4}$ real size).

formed be broken within the portion *c* by the finger or a rolled piece of blotting-paper, the unbroken portion of the film will contract and stretch the thread into a beautiful curve. If the thread be fixed only at *a* and

held by the finger at b , its length may be altered at will, but the contraction of the film will always stretch it so as to form an arc of a circle. If a small loop is made at the end of the thread, fig. 26, C , D , the latter fixed at a , and the film broken at b , the thread of the loop will form a complete circle within the ring.

Very beautiful cohesion figures may be formed if small wire frames are immersed in soap-water and then withdrawn. A triangular frame, fig. 27, made of six little wire rods, ab , ac , ad , bc , cd , and db , provided with a handle ae , exhibits after immersion six thin films which are all directed towards the middle of the frame, where they intersect.

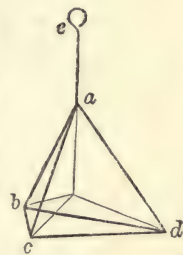


FIG. 27
(an. proj. $\frac{1}{3}$ real size).

A frame of twelve equal wires, fig. 28, representing the edges of a cube, produces by immersion a small

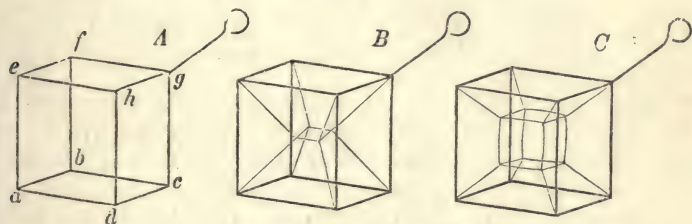


FIG. 28 (an. proj. $\frac{1}{3}$ real size).

rectangular film in the middle, which is joined to the edge by twelve plane surfaces. If the frame is now again slightly immersed so that the lower edges, ab , bc , cd , da , touch the surface of the liquid, a small bubble is formed which, when the frame is again raised, moves to the middle, taking the shape of a cube with convex faces (fig. 28, C).

Another series of experiments on cohesion figures may

be made by means of two wire rings, one having a handle the other three small legs. Both rings are wetted with soap-water, and the one with the handle held horizontally above the other which stands on its legs on the table. A soap-bubble is now blown in the usual manner by means of a clay tobacco-pipe between the rings, and with a little care the bubble can be made to attach itself without breaking to both rings, fig. 29, *A*. The pipe is then cautiously withdrawn.

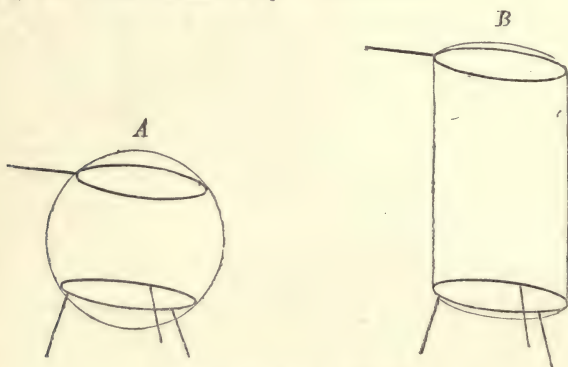


FIG. 29 (*an. proj.* $\frac{1}{4}$ real size).

A contrivance, usually called a *retort stand*, is convenient for fixing the upper ring in a definite position. A vertical rod, fig. 30, is fixed in a rectangular board which forms the foot of the stand. A ring capable of sliding along this rod carries a horizontal fork of wood for holding apparatus of various kinds, which may be firmly clamped between the prongs by means of the screw *c*. To render the grip less hard, and thus to prevent the breaking of glass vessels, the ends of the fork are lined inside with cork. The fork is fixed to the sliding ring by the nut *b*, and may be placed at any required height by the screw *a*. The figure shows a glass tube clamped in a vertical position, but the fork may be turned by loosening the nut *b*, and anything held by it may thus be inclined as required.

If the upper ring is supported by the fork of the retort stand, and made to slide slowly upwards, the soap-bubble, which was originally spherical will become

elongated and form a cylinder with a spherical surface at each end, fig. 29, *B*. If the ring is further raised

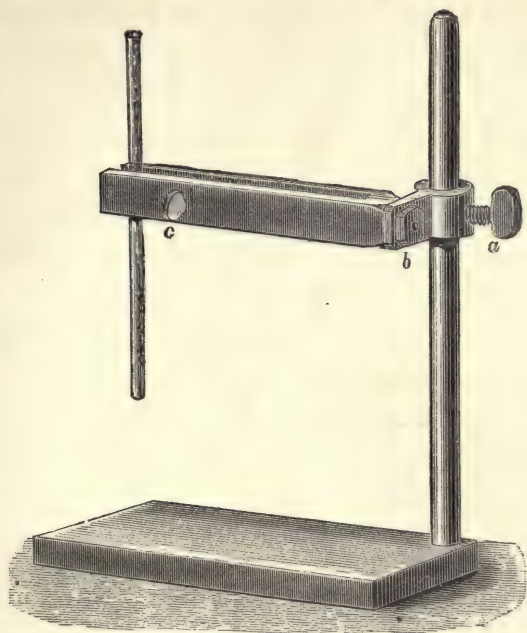


FIG. 30 (*an. proj.* $\frac{1}{5}$ real size).

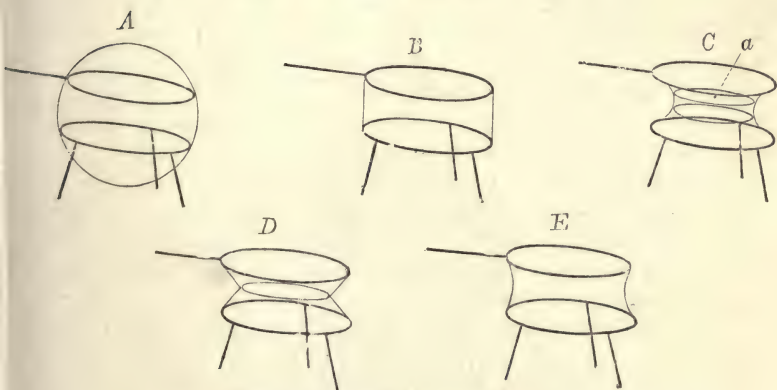


FIG. 31 (*an. proj.* $\frac{1}{4}$ real size).

the cylinder becomes more and more narrow at the middle and finally breaks, often forming two separate

round bubbles. The tendency of the liquid film to contract may be well studied by placing the rings rather close together; a bubble is blown between them until it adheres to each ring, the air is then gradually sucked back again and the pipe withdrawn. During this operation the bubble assumes successively the forms represented in fig. 31, A, B, and ; and if the pellicle *a*, fig. 31, C, is destroyed by touching it with the finger, the remaining portion of the film will assume the form shown in fig. 31, D. Finally, if the last plane pellicle is also destroyed, the remainder takes the shape represented in fig. 31, E.

Bubbles blown from soap-water do not last long, because the small quantity of water in them evaporates very rapidly. But the liquid prepared in the following manner evaporates very slowly, and the films formed from it therefore last much longer, frequently several hours, if the air around them is perfectly quiet. Take 400^{cc} of cold water that has previously been boiled, and put into it 10 grammes of Castile soap, cut up fine. Put this into a wine-bottle and set it in hot water in a saucepan on the hob; let it remain there an hour or so, shaking it up occasionally till the soap is dissolved. Next, let the liquid stand quietly for a few hours, for the impurities and colouring matter to settle; pour off the clear liquid, and add to it 270^{cc} of glycerine (about 335 grammes), shaking the whole thoroughly well. Commercial glycerine is frequently impure; for this solution the glycerine should be colourless and have nearly the consistency of treacle.

These experiments, especially those with the rings, do not usually succeed at once; the rings must be moistened with great care, and the experiment should be attempted repeatedly. The beauty and duration of the figures when obtained will, however, amply repay a good deal of trouble.

The wire-frames, if purchased, should be of iron wire, to which the liquid easily adheres, especially when the wire is slightly oxidised. Brass wire, although inferior, has the advantage of being more easily soldered by an inexperienced hand. Solder is prepared by melting 3 parts by weight of tin with 2 parts by weight of lead in a melting ladle (a round ladle made of sheet iron with a wooden handle). The molten mixture is stirred with a

piece of wood and then poured out upon a flat horizontal surface, such as an old plank or a flat stone, that it may form a thin cake from which small pieces may be cut with a strong knife or a pair of cutting pliers. It is better to pour the liquid solder from a height of about 1^m in a small stream into a pailful of water, which is at the same time stirred with a rod or a bundle of twigs; the solder is then obtained in a granulated state, thus saving the trouble of further dividing the mass afterwards.

Metals only adhere to each other if they mutually present bright surfaces. Hence a piece of metal heated for the purpose of soldering does not take the solder—or as it is termed, the solder does not run—unless the metal is treated with a liquid which dissolves the layer of oxide which usually covers the surface. A solution of chloride of zinc, or 'soldering water,' serves best for this purpose. Into a glass capable of containing about 250^{cc} (nearly 8 ounces) of water, pour 50 grammes of crude commercial hydrochloric acid, and gradually add chippings of zinc, which may be obtained from a tin-smith. At first a brisk effervescence will accompany the solution of the zinc, but afterwards it proceeds more slowly. Add more zinc until some of it remains undissolved even after a few hours. Then add to the solution 10 grammes of powdered sal ammoniac, which is quickly dissolved if the liquid is stirred. Let the whole stand quiet for some time, and pour off the clear liquid into a small bottle for use.

When a liquid is to be transferred from one vessel into another, it can be prevented from running down outside of the vessel, by slightly greasing the lip and pouring it down a rod which is placed against the edge in the manner represented in fig. 32.

By making the solution at once in a larger bottle the necessity of transferring it from one vessel into another may be avoided. The zinc must in that case be cut up fine to make it pass through the narrow neck of the bottle, and care should be taken not to bring a flame near the mouth of the bottle as long as the solution is effervescing; the gas which issues forms an explosive mixture with air, which if lighted would perhaps detonate loudly and destroy the bottle.

No dangerous explosion can take place if the solution is made in

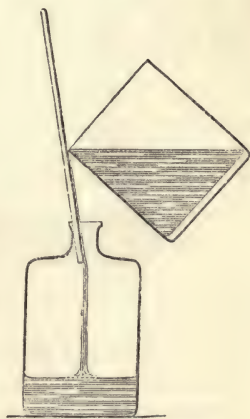


FIG. 32 ($\frac{1}{5}$ real size).

an open tumbler. The soldering water is somewhat poisonous, and if dropped upon articles of clothing produces spots, frequently of a red colour; they may be removed by touching the spots with a solution of ammonia carbonate (spirit of hartshorn). The wire for the frames should be about 1.5mm thick. The required lengths are best cut off with a pair of strong and sharp nippers, fig. 33 B,

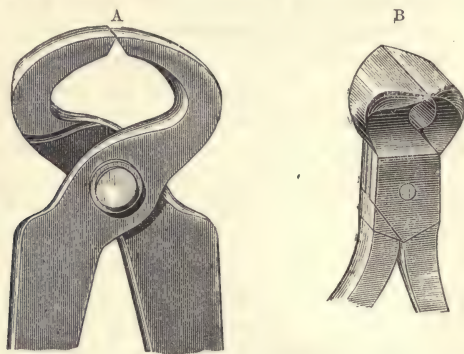


FIG. 33 ($\frac{2}{3}$ real size).

which should only be used for wire-cutting; for ordinary purposes, such as drawing nails, breaking objects, a common pair of pincers, fig. 33 A, should be used.

To form the rings, fig. 26, nip off a piece of wire about 30 or 32cm long. With the round pliers make first at one end the little hook, and bend the wire at right angles at *a*. The ring itself is then shaped by the fingers with the help of the flat pliers, until the other end is opposite to *a*. Moisten the end, and the part at *a* opposite to it with the soldering water, either with a hair pencil or a feather from which the plume has been cut away all but a small portion at the end. Hold the moistened part *a* in the flame



FIG. 34 ($\frac{2}{3}$ real size).

of the spirit lamp, or Bunsen's burner, and place a piece of solder not larger than a lentil upon it. This may be done with a pair of tweezers or forceps (fig. 34), or a piece of wire may be moistened at one end with soldering water, heated, and rapidly brought into contact with a small piece of solder, which will then firmly adhere to the wire. When the solder adheres at the bend *a*, the other end

of the wire is also brought into contact with it, and when a firm adhesion is obtained, the ring is removed from the flame and allowed to cool, the parts being kept in the proper position until the solder becomes solid. Finally, the soldering water which may have remained is removed by washing. As the whole ring becomes very hot during the operation, the straight handle of it should be placed between flat pliers and held in the left hand, leaving the right hand free for the soldering and directing the free end of the wire with the flat tweezers.

The frame, fig. 27, is made thus. A piece of wire, about 36^{cm} long, is first somewhat straightened with the fingers and flat pliers, and then divided, by compasses or measuring rule, into 6 equal parts, the divisions being marked by a slight scratch with a three-cornered file; if the scratch is made deep, the wire will break if bent at that place afterwards. The first part, one sixth of the whole length, forms the handle *ae*; at *a* the wire is slightly bent, the second point of division forms then the angle at *b*, the third at *c*, and the fourth returns to *a*, *abc* forming an equilateral triangle. At *a* the wire is again bent downwards, the fifth division being placed at *d*, and the end at *b*. The whole is now adjusted until the distance between *c* and *d* is nearly equal to the length of the other sides, *ab*, *bc*, etc., and the corners are now soldered together, first *a*, then *b*. Finally, a single piece of wire of the proper length is soldered to *c* and *d*.

The cubical frame, fig. 28, A, requires a piece of wire 60^{cm} long, divided into 10 equal parts. The first of these forms the handle, the four next supply the sides *gh*, *he*, *ef*, *fg*; the sixth forms the side *gc*, and the square *cdab* is formed by the remaining four parts, the end of the wire thus returning to *c*. Solder first at *a*, then at *c*, and insert finally three single pieces each 6^{cm} long for the sides *hd*, *ea*, and *fb*.

The ring with the legs is shaped like the other rings, but the projecting piece is made shorter and forms one of the legs; to supply the other legs two pieces of equal length with it are soldered to the ring separately.

Iron does not take solder so well as brass; but if the iron wire is very bright, or polished with emery-powder, the frames may be easily made of iron wire, with a little patience.

5. *Porosity*.—Many bodies, for instance a piece of sponge, pumicestone, bread, etc., do not fill space completely, but between the particles of matter of which

these bodies consist, the unassisted eye perceives many interstices of variable size, termed *pores*. The property of bodies to contain pores between their particles is called *porosity*. In bodies like wood, cork, paper, sandstone, the pores are much smaller and can only be seen with a magnifying glass. Many other bodies, even when thus examined, present no visible pores. Nevertheless such interstices exist, although they are very small. Thus hard stones are often coloured for commercial purposes; this would be impossible if the colouring matter could not penetrate into their pores. Again, by using great pressure, liquids may be forced even through metals.

Even in liquids, where we should least expect pores, their existence may be demonstrated. A small bottle with ground stopper, of about 100 or 200^{cc} capacity, is filled half with water; alcohol is then poured in cautiously along the side of the bottle, so as not to mix the two liquids, which may be seen to be separate by bringing the middle of the bottle to the level of the eyes. The bottle should be filled so that a few drops of alcohol are pushed out when the stopper is inserted, and no air-bubbles should remain in the bottle. In order to be sure that no more alcohol leaves the bottle, that which has run out should be carefully wiped off with a cloth, without removing the bottle from the table on which it stands.¹ Now raise the bottle between thumb and fingers, press the forefinger firmly upon the stopper and invert the bottle several times so as to mix the two liquids thoroughly. Numerous tiny bubbles will be

¹ Alcohol injures the polish of the table; it is therefore better to place the bottle upon a china plate, if the table is polished.

produced which combine to form a single large bubble, free from air if the stopper closes airtight, or containing air if, as frequently happens, the stopper does not close perfectly. In any case, however, the space now occupied by the two liquids when mixed is smaller than that filled by them before they were mixed. The two substances have, as it were, penetrated each other, which could not happen had there been no interstices. The same phenomenon may be observed in mixing many other liquids.

The separation of the water and alcohol in this experiment, before they are mixed, may be shown by colouring the water with a solution of aniline-red (magenta). About 50^{cc} (40 grammes) of alcohol are poured over one gramme of the magenta, which in the solid state is of a golden-greenish colour. The solution is allowed to stand for a few hours, and is occasionally well shaken. One cubic centimetre of it is sufficient to give a red colour to two litres of water.

Put a few grains of iodine¹ into a small flask of the size represented in fig. 21, close the flask with a good cork, and heat it gently; the iodine gives off beautiful violet vapours, which fill the bottle. This experiment proves that air is highly porous, for the diffusion of the iodine vapours is not prevented although the flask is filled with air. The porosity of gases may also be deduced from their high compressibility (art. 3). It is impossible to conceive that the ultimate matter of which these bodies consist can alter its volume, and it follows that if a body be compressed, it is not the material particles themselves which become smaller, but the pores between them. Not only gases, but

¹ Iodine is *very poisonous*; it forms bluish-black lustrous scales, and produces brown stains upon the skin, paper, and most organic substances.

al solid and liquid bodies, may be compressed into a smaller space by adequate pressure; hence they all possess pores. It will be shown hereafter, in the chapter on Heat, that the volume of bodies may be diminished even more easily by cooling than by pressure.

6. *Divisibility*.—All bodies may, by proper means (for instance, by cutting, pounding, etc.), be divided into smaller and smaller parts. The divisibility of bodies which are soluble in liquids may be carried very far by diluting their solution. As has been mentioned previously, one cubic centimetre of the red aniline solution, which contains 0.02 gramme of colouring matter, will give a beautiful red colour to 2 litres of water; one cubic centimetre of this water will therefore contain (since one litre is equal to 1000^{cc}) the $\frac{1}{20000}$ th part of 0.02 gramme, that is, the one hundred thousandth part of a gramme of aniline red, and a whole cubic centimetre is by no means required to show distinctly the red colour. A piece of a fine glass tube, about 10^{mm} long, and 1^{mm} wide, may be filled with the liquid by immersing it into it; if held against the light, the liquid in the tube appears very distinctly red. Now a cylinder of 1^{mm} in diameter, or having a radius of 0.5^{mm} and a length of 10^{mm}, has a volume of $0.5 \times 0.5 \times 3.1416 \times 10 = 7.854$ cubic millimetres.

The quantity of liquid in the tube is therefore not quite the $\frac{1}{127}$ th part of a cubic centimetre, (for 1 cubic centimetre = 1000 cubic millimetres, and $\frac{1000}{7.854} = 127.32366$), and since one cubic centimetre of the liquid does not contain more than $\frac{1}{100,000}$ of a

gramme of the colouring matter, the whole liquid in the tube will contain less than the $\frac{1}{12,000,000}$ th part of a gramme. A square centimetre of the finest gold-leaf weighs about $\frac{1}{5,000}$ th of a gramme, and a small piece of it, much less than a square millimetre, hence much less in weight than the $\frac{1}{500,000}$ th part of a gramme of gold, is easily visible to the naked eye. Portions of bodies, much smaller still than those described, may be rendered visible by proper means; but whatever means may be employed, they are insufficient to divide bodies into the smallest particles of which they consist.

These smallest indivisible particles are called *molecules*, and the forces of cohesion and expansion, which induce these particles either to cohere or to recede from each other (art. 4), are consequently termed *molecular forces*.

A narrow piece of glass tubing for this experiment may be obtained by drawing out a wider tube before the lamp. The middle portion of a piece of tubing, 12 or 15^{cm} long, and from 5 to 7^{mm} wide, is heated in the flame of the spirit lamp until it is quite soft; it is then quickly removed and pulled with both hands in the direction of its length until the middle portion has the required width. After cooling, this portion is removed by making a scratch with the three-cornered file at each extremity, and breaking the intermediate portion away. The tube should be constantly turned on its axis while it is in the flame, otherwise it will not be heated with sufficient uniformity, and cannot be drawn out properly.

7. *Gravity. Absolute and Specific Weight.*—A stone cannot be lifted from the ground, or a book from the table, without using a certain amount of force, which is less or greater according as the mass of the body is less or greater. If left to itself the raised body will speedily fall back again towards the ground until prevented from falling further by some obstacle, that is, until it

has again come to rest upon the ground, the table, or some other support. The cause of this motion of all bodies towards the earth, the attractive force exerted by the earth upon all bodies, has been termed *Gravity*, and the fact that each body is subject to the action of gravity is expressed by saying that each body possesses *Weight*. The direction in which this force acts, that is the direction towards the centre of the earth, is called *vertical*; every line at right angles to the vertical direction is called a *horizontal* line.

The greater the mass of a body, that is, the greater the number of material particles which it contains, the more is it attracted by the earth, the greater is the force required to lift it, the greater is the violence with which, when left to itself, it falls back to the earth, and the greater is the pressure which it exerts upon its support when at rest. The total amount of the earth's attraction for a body, the magnitude of the pressure which it exerts upon any support, is termed the *weight*, or more precisely, the *absolute weight*, of a body. The gramme-weight is a very convenient unit of weight in many calculations, and therefore much used in physical determinations.

One *Gramme* (1^{gr}) is the weight of one cubic centimetre of water.¹ A weight of 1000^{gr} is hence the weight of 1000^{cc} or a litre of water, and is called a *Kilogramme* (1^{kgr}). The subdivisions of the gramme have special designations: one tenth of a gramme is called a *Decigramme*; $\frac{1}{100}$ th of a gramme, a *Centigramme*; $\frac{1}{1000}$ th of a gramme, a *Milligramme*. A milligramme is the weight of a cubic millimetre of water.

¹ The influence of temperature, in consequence of the expansion of water, is discussed in the chapter on Heat,

A balance for the following experiments should be capable of carrying at least one kilogramme, and of indicating a difference of $\frac{1}{10}$ th of a gramme when the weights in both scales are comparatively small. Such a balance may be bought for a small sum. A common grocer's balance is also suitable for many purposes, but is usually not very delicate. The weights required range from 0gr·1 to 1kgr. In any case a set of the following weights made of brass should be purchased, viz.:

20gr; 20gr; 10gr; 5gr; 2gr; 2gr; 1gr; 0gr·5; 0gr·2; 0gr·2; 0gr·1; while the larger weights of 500gr, 200gr, 200gr, 100gr, and 50gr may either be purchased or made of lead. Procure for this purpose a cylindrical piece of wood, 3cm thick and 5cm long, from the turner, or cut one with a knife. Wrap a strip of strong packing paper, from 6 to 12cm broad, and 40 or 50cm long, round the cylinder, so that it projects at one end, and tie it firmly with thread. A paper mould is thus obtained for pouring in the lead. Each time a little more metal must be taken than the weight to be formed, as a little is lost in the melting, which may be performed over a common fireplace in a capacious ladle of sheet-iron with a wooden handle. The film over the molten lead should be removed with a splinter of wood before pouring the metal into the mould; the wooden cylinder should also be heated near a fireplace as strongly as possible without burning it, for if the wood is not perfectly dry bubbles of vapour are produced, and passing into the liquid metal render it spongy. The paper must be renewed for each weight which is to be produced. The pieces are corrected to the exact weight which they are to represent by careful cutting, and finally cautious scraping. If you have no other weights than the above-mentioned small set, make first a 50-gramme piece by placing into one scale $20 + 20 + 10 + 5 + 2 + 2 + 1 = 60$ gr, and thus weighing out 60gr of lead. The cast piece is then corrected to 50gr ($20 + 20 + 10$), and with the help of this new weight and the others now make a 100gr weight, and so on. All these weights have a diameter of 3cm, they are easily distinguished by their different heights, and therefore require no particular marking. The 500gr piece will have a height of about 7cm, that of 50gr of about $\frac{2}{3}$ cm. The lead is generally bought in rather large pieces, but in order to weigh out any required quantity it is convenient to granulate it, by pouring it in a molten state into water, in the manner previously described in the case of zinc.

Having procured a balance and the necessary weights, the next step is to provide yourself with a number of liquid measures, which are frequently required, and may all be prepared by weighing out

quantities of water. To perform this operation conveniently a washing-bottle is required, and a support for suspending your balance at some height. The wooden support, fig. 35, is best

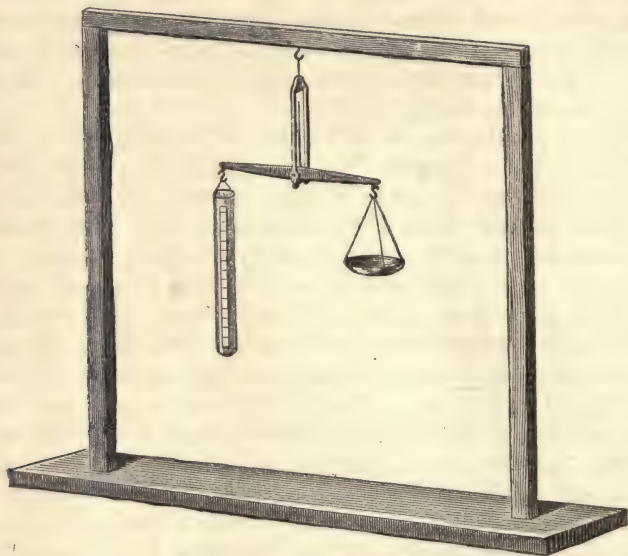


FIG. 35 (*an. proj.* $\frac{1}{10}$ real size).

made by a joiner; it is very useful for many experiments. The foot should be at least 80^{cm} long, 20^{cm} wide; the frame 60^{cm} in height and width; the bars themselves should be of hard wood, 2^{cm} square. If the whole can be made somewhat larger it is so much the better. Into the upper crossbar a number of small iron or brass hooks are screwed, which may be bought at any ironmonger's. A hole, smaller than the screw, is first made with a gimlet, and the screw is slightly greased with tallow, before it is screwed into the hole.

The washing-bottle is used for producing a fine jet of water. A flask, usually of the form shown in fig. 36, has two tubes adapted to it air-tight, by means of a twice perforated cork. The tube *a* is bent at an obtuse angle, the tube *b*, which reaches nearly to the bottom of the flask, is bent at an acute angle, and ends externally in a fine point, having an aperture of only about 0^{mm}.5. This extremity should not be too thin in the glass; it is therefore better to make the tube very hot before drawing it out, and to draw it out only about as far as shown in fig. 37. The narrow portion is then cut by the file in the middle, and broken off. The

bending of tubes is a very easy operation ; about an inch is heated in the spirit flame, the tube being constantly turned round on its axis in order that all parts may be equally heated, and the ends gently

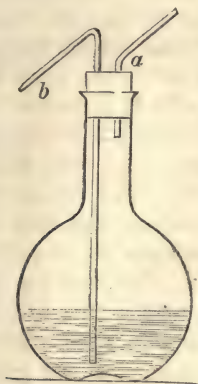


FIG. 36 ($\frac{1}{6}$ real size).



FIG. 37 (real size).

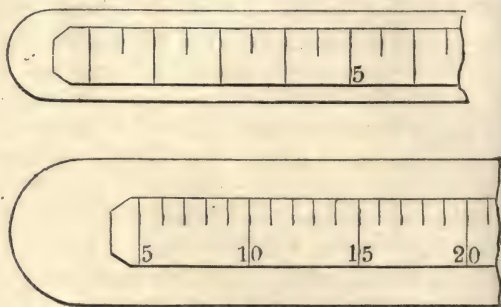
inclined towards each other when the heated part is sufficiently soft. The tube should be drawn out before it is bent, for afterwards it cannot be conveniently turned. The vessel is filled with water, the mouth applied to the tube *a*, and air being forced into the flask the water issues in a fine jet from the narrow orifice of the tube *b*.

For small liquid measures common test-tubes may be employed ; they are thin cylindrical vessels of glass with rounded bottoms, the edges of the open end being turned outwards. A test-tube of about 12^{mm} width and 12^{cm} length is divided into cubic centimetres and half cubic centimetres up to a capacity of 10^{cc} ; another, of 20 or 25^{mm} width and 20^{cm} length, may be divided into whole cubic centimetres up to a capacity of 50^{cc}.

A slip of writing paper 1^{cm} wide is pasted with gum, or better with isinglass which has been dissolved in boiling water, down the length of such a tube. When dry, a double thread is tied round the tube under the edge, in order to suspend it to one extremity of the beam of a balance, from which the scale-pan has been removed, fig. 35. Shot or sand is put into the other scale until equilibrium is restored. If the scale-pan is not very light, it may, without additional weights, be heavier than the test-tube ; in this case a small piece of lead or a stone is suspended by the side of the test-tube, and then equilibrium is produced by shot or sand placed into the opposite scale-pan. Weights are now placed in the scale one by one, and each time water is poured into

the tube from the jet of the washing-bottle until equilibrium is restored. The height of the water in the tube is marked by a pencil line on the paper. In the smaller tube quantities of one, two, three, etc., up to ten grammes, are successively weighed out, in the larger tube first 5 grammes, then 10, etc., up to 50 grammes.

The surface of water in a glass vessel is not quite level, but forms a concave '*meniscus*.' To avoid errors the same boundary of the meniscus should always be read off; it is better to take the lower, *a* in fig. 38, because it is best defined. It is also necessary to hold the measure always perpendicularly, not only while marking off the divisions, but also whenever any liquid is measured by the graduated scale. When the larger divisions have been determined, they may be divided by a pair of compasses into subdivisions; the lines are then neatly drawn with Indian ink, and the paper, after the ink has become dry, washed over with a thin solution of gum arabic, and finally, when again quite dry, with varnish. The varnish protects the paper from moisture, and the gum prevents the varnish from penetrating the paper, and thus rendering the divisions unsightly. The lowest division in each graduated tube

FIG. 38 (*real size*).FIG. 39 (*real size*).

cannot be subdivided into equal parts on account of the rounded shape of that part of the vessel. Fig. 39 shows the arrangement of the whole graduation.

Divisions which are etched on the glass are neater and more durable than those drawn on paper. Such graduated measures are not very expensive, and may be purchased, while larger measures for liquids require no great accuracy, and may easily be made by pouring into a glass vessel with stout sides gradually 50, 100, 150, etc., up to 500^{gr} of water, and marking the height of the liquid each time by a scratch with the three-cornered file.

Equal volumes of different bodies have often very

different weights. A piece of lead is much heavier than a piece of wood of the same size. In many cases it is necessary to express numerically the ratio of the weights of bodies; this is done by comparing the weight of each body with the weight of an equal volume of water.

The weight of the unit volume (1^{cc}) of any substance is its ABSOLUTE specific gravity.

The number which expresses how many times heavier a body is than an equal volume of some particular substance chosen as a standard of comparison, is called the RELATIVE specific gravity of that body.

The standard substance with which the specific gravities of solid and liquid bodies are usually compared is WATER. The term 'specific gravity' will hereafter be used for 'relative specific gravity.'

A piece of glass which weighs 48^{gr} has a volume of 20^{cc} ; hence an equal volume of water weighs 20^{gr} , and the specific gravity of glass is therefore 2.4 , for $20 \times 2.4 = 48$, or $\frac{48}{20} = 2.4$. *The specific gravity of*

a body is found by dividing its absolute weight by that of an equal volume of water. The specific gravity of bodies

lighter than water is a proper fraction. If the weight of a cube of cork, with edges each 2^{cm} in length, and hence a volume of $2 \times 2 \times 2 = 8^{\text{cc}}$, is found to be 2^{gr} , its spec. grav. is 0.25 , for 8^{cc} of water weigh 8^{gr} ,

and $\frac{2}{8} = 0.25$. The specific gravity is thus an abstract

number; but it will be seen that it also expresses the absolute weight in grammes of a cubic centimetre of the body, and the weight of a cubic decimetre of the

body in kilogrammes, since 1^{cc} of water weighs 1^{gr} , and 1 cubic decimetre weighs 1 kilogramme.

To determine the specific gravity of a body we must find its absolute weight by means of the balance, and the weight of an equal volume of water; this may be done in various ways, of which the following is an instance.

Fill a vessel which has a lateral spout, fig. 40, *a*, with water, and allow the portion above the spout to

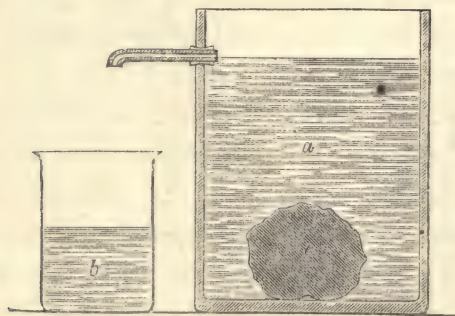


FIG. 40 ($\frac{1}{5}$ real size).

run out. Weigh an empty tumbler, *b*, place it under the spout, and immerse the body *c*, in the water in *a*, by tying it to a silk thread and letting it slowly down to the bottom. A volume of water, equal to that of the body, will be displaced by it, and will run out through the spout. When all the displaced water has collected in the vessel *b*, this is again weighed, and the increase in weight is the required weight of a volume of water equal to that of the body. Thus, suppose we require the sp. gr. of a piece of mineral. Let its weight be $116^{\text{gr}}.1$, the weight of the empty vessel *b*, 48^{gr} , and with the displaced water 91^{gr} . The weight of the displaced water is therefore $91 - 48 = 43^{\text{gr}}$, and the

sp. gr. of the mineral $\frac{116.1}{43} = 2.7$. Instead of weighing the displaced water, it may be measured in a graduated vessel. Thus if it is found that a piece of brass which weighs 160^{gr} has displaced 20^{cc} of water, the sp. gr. of the brass will be $\frac{160}{20} = 8$, for 20^{cc} of water weigh 20^{gr}.

A somewhat large tumbler, having a hole bored near the upper edge, may serve for the last experiment. The hole is bored with a round file, of which the point is broken off, so that a round surface of from 2 to 3^{mm} in diameter is obtained. The edge of this round surface is used for drilling, the file being held with the right hand in a slanting direction, and the thumb being kept quite close to the broken end of the file, in order to increase the pressure and also to prevent the file from slipping through the finished hole and breaking the glass. File and glass must, during the operation, be frequently wetted with water or, better still, with oil of turpentine. After piercing the glass completely by the point, the hole is enlarged by slowly turning the file from right to left, in the manner in which a screw is drawn, repeatedly moistening the orifice and the file. If a wider orifice is required than the thickest part of the file, the latter is used simply for widening it by filing equally all round, care being taken not to make the aperture angular by working too long at any point. It is advisable to practise the operation first on a few pieces of broken glass. A small piece of bent tubing is now inserted into the vessel by means of a short india-rubber tube, half of which is first passed into the aperture, into which it must fit tightly, the greased glass tube being then cautiously pushed with a turning motion into the india-rubber tube. The end of the bent tube must be rounded before the lamp.

The specific gravity of a liquid is found by weighing a little flask provided with a well-ground stopper, first filled with water and afterwards with the liquid. Care being taken that at each weighing the flask be completely filled with the liquids, the weights of equal volumes of

both of them are thus obtained. For instance, suppose the flask to weigh empty 60^{gr} , filled with water 130^{gr} , filled with a strong solution of common salt 144^{gr} ; the bottle holds then $130 - 60 = 70^{\text{gr}}$ of water, and $144 - 60 = 84^{\text{gr}}$ of the solution, which has therefore a spec. gr. of $\frac{84}{70} = 1.2$.

In Table I., at the end of this book, will be found the Specific Gravities of some of the most important substances.

MECHANICS

OR

THE EQUILIBRIUM OF BODIES (STATICS), AND
THE MOTION OF BODIES (DYNAMICS).

8. *Inertia*.—A body is said to be at *rest* when it constantly keeps the same position in space ; if it changes its position it is said to be in *motion*. No body with which we are acquainted is absolutely at rest. The earth moves round the sun, and turns at the same time about its axis ; all bodies upon the earth are thus in motion. Hence, when bodies are said to be at rest, we mean that they maintain their position in relation to the earth ; in this sense a building or a tree is at rest, while a moving carriage or a running man is in motion ; and it is in this sense that the term rest will have to be understood in the succeeding articles.

A body has a *motion of translation*, if all its particles occupy successively different positions ; otherwise the motion is *rotatory* or *vibratory*, the body as a whole maintaining in these cases its position, while portions of the body change their position in space in consecutive times. The motion of a rolling carriage, of a running man, of a cannon-ball fired from a gun, is a motion of translation ; the motion of a wheel, of a mill-stone, of a boy's top, is rotatory ; the motion of the pendulum of a clock, of a sounding violin string, is vibratory. The motion of the earth is at the same time a motion of translation and a motion of rotation.

By observing bodies at rest, such as a piece of furniture, a tree, a stone, we have many opportunities of satisfying ourselves that they do not change their state of rest without some external cause, that they do not commence moving of themselves. On the other hand, the observation of moving bodies seems to lead at first to the conclusion, that all moving bodies gradually come to rest. A stone propelled along the road moves over a short distance, but soon stops again ; if thrown along a sheet of ice, it will pass over a longer space, yet it will come to rest again; it is the same with a cannon-ball projected from a gun, although it may pass over several thousand yards before its motion ceases. But although in all these cases the motion comes to an end, it would be erroneous to conclude that the bodies stop of themselves, for definite causes may be shown to exist which make the motion gradually slower, and finally destroy it altogether. One of these causes is especially the friction which takes place between a moving body and its support. The greater the friction the sooner is the motion of a body stopped; this is the reason why the stone moves over a greater distance on a smooth sheet of ice than on the rough road. But a moving body has further to overcome the resistance of the air in which it moves. The more the friction and resistance of air are diminished by artificial means, the longer the motion of a body lasts, and if it were possible to remove completely every obstacle to motion, it could be proved by actual observation, that a moving body is of itself as incapable of stopping when in motion, as it is incapable of commencing to move of itself when at rest. Friction and resist-

ance of air have comparatively little effect upon the motion of a round body, such as a boy's top, when it turns on its axis. A heavy disk of lead, fig. 41, with an axis of steel which ends in a blunt polished point, spins for about three quarters of an hour, if allowed to move in the cavity of a watch-glass. In a space from which the air has been removed, it even continues its motion during several hours.

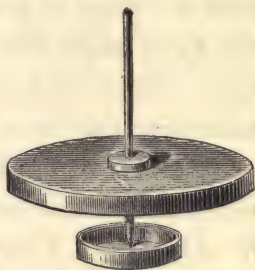


FIG. 41 ($\frac{1}{4}$ real size).

The earth is a rotating body which meets with no friction, and its motion, as observed by the rising and setting of the heavenly bodies, continues without interruption or change. Nor is the earth's motion counteracted by the resistance of the air, for the earth and its atmosphere form together one body which moves as a whole in space.

Thus a body cannot change its state without some external cause, and every such cause requires a definite time for producing its effect. This effect can take place very rapidly, but never instantaneously, or all at once. Let a body of moderate size, a stone, or a piece of wood, a few centimetres in diameter, be placed upon a sheet of paper; if the paper is slowly drawn along the table, the body will remain on the paper and follow its motion. The force which moves the body is the friction between it and the paper; this force is small but sufficient for giving a slow motion to the body. If the paper be pulled with a rapid jerk, the body will not move with it; its motion is imperceptible while the paper slides away from underneath it. To give to the body the more

rapid motion which the paper now has, either a greater force would have been required than that which friction exerts in this case, or the mass of the body must be diminished. If a piece of wood were glued to the paper, or a flat piece of cork be placed upon it, that is, if either the force which acts upon the body be increased, or its mass diminished, it will readily follow the quicker motion of the paper.

A body at rest offers resistance to being set in motion; this resistance is greater the greater the mass of the body. Conversely, a moving body offers resistance to being brought to rest; this resistance is also greater the greater the mass of the body, but besides, it is also greater the more rapid the motion. This property of bodies, to resist changes of state, is called their *inertia*. If inertia, or any other resistance, is overcome, *mechanical work* is performed. To put a ball into motion, a certain amount of work must be done. The ball takes up the work, which becomes as it were stored or *accumulated* in it, and enables the ball itself to perform work, to overcome resistances. The work accumulated in the ball is, when it rolls along, soon exhausted by having continually to overcome the resistance of friction, but if it should strike upon another ball, a great portion of the accumulated work will be at once expended in overcoming the inertia of the second ball, that is, in setting it in motion. The greater the violence of the impact, or the greater the amount of accumulated work in the first ball, the greater will be the velocity with which the second ball will begin to move.

A few simple experiments will illustrate these facts. Place a number of wooden draughtsmen upon each

other so as to form a small perpendicular column. If the lowest man is pushed gently along, the whole column will move forward; the friction between the men being sufficient to communicate the motion from each man to the next above. But if the lowest is pushed somewhat more quickly, the second does not acquire the same velocity, but will move more slowly, the next still more slowly, and so on, till the column is upset (fig. 42).

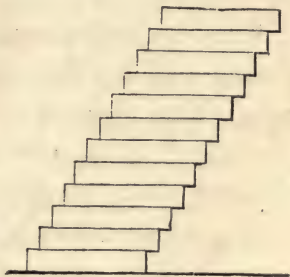


FIG. 42 ($\frac{1}{2}$ real size).

Finally, if the lowest man be rapidly struck with a thin but heavy body, for example the back of a dinner-knife, it will be seen to fly away, while the column remains undisturbed and merely falls perpendicularly by a height which is equal to the thickness of the removed piece. The experiment succeeds best if the knife be placed entirely on the table, so as to move it in a perfectly horizontal direction. With a little practice pieces may thus be removed from the middle of a column without disturbing it. If a playing-card be placed upon the mouth of a bottle, and a coin sufficiently small to fall through the neck be laid upon it, the playing-card may easily, in the same manner as the draughtsman be set into a rapid motion by a sudden jerk with the finger, while the coin drops into the bottle. Here the lighter card receives sufficient velocity from the finger, while the heavier draughtsman requires the heavier knife, that is a body which is more capable of accumulating work.

1. *General Mechanics, and Mechanics of Solid Bodies.*

9. *Force and Mass.*—It has been shown in the preceding article that no change in the state of bodies can take place without special causes. The causes which produce or change motion are called *forces*. When we observe that unsupported bodies move towards the earth, we say that the earth exerts an attracting force upon bodies, and call this force *gravitation*. The weight of bodies is a measure of the force of gravitation, and other forces are estimated by comparison with it.

The laws which regulate the relations between bodies, the forces that act upon them, and the motions produced by these forces in the bodies, may be investigated by the apparatus represented in fig. 43.

A massive wheel of brass, *R*, of 100^{gr} weight, with a thin axis of steel, *a a*, is easily moveable between the points *s s*. The posterior point is fixed, but the anterior may be adjusted in the proper position by the screw *S*, and then clamped by the nut *G*. The axis must revolve with the greatest ease. If it rattles while in motion, the nut *G* must be unclamped by turning it to the left, until it is about 1 millimetre distant from the brass frame, to which it is clamped; the screw *S* must then be properly adjusted and held in its correct position by the hand while the nut *G* is again firmly clamped. A fine silken cord passes over the wheel and carries two weights *P P*, at its extremities. Each weight is 70^{gr}, and is provided with two small hooks on opposite sides. Besides these, four larger weights of

98^{gr} each, two of 1^{gr} each, and one of 4^{gr}, having the form shown at *u*, are required. A perpendicular scale, 1^m.5 long, is divided into half-decimetres, and the brass plate *B*, which is suspended by three threads, and

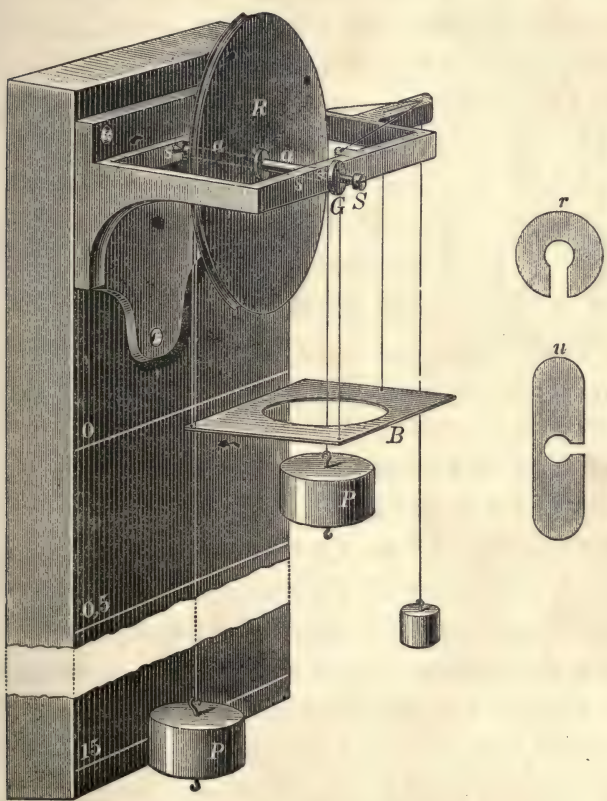


FIG. 43 (*an. proj.* $\frac{1}{2}$ real size).

has a hole in the middle, may be moved along the scale and held in front of it at any required height by means of a counterpoise.

An apparatus is also required for measuring time. If no clock is at hand which audibly beats seconds, a pendulum, fig. 44, may be used, consisting of a leaden

weight suspended by a cord, and carrying below a very small weight attached to it by a silk thread, which passes through a short glass tube.

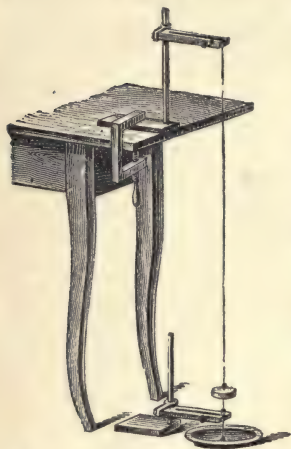


FIG. 44 (*an. proj.* $\frac{1}{2}$ *real size*).

The small weight rests on a hard support, when the pendulum is not in motion; but at each vibration it is raised and again lowered upon the support with a distinctly audible sound.

The two weights of 70^{gr} each being suspended by the cord which passes over the wheel, the whole is in equilibrium, and at rest. The force of gravity acts in this case equally upon both sides, and the two equal but opposite forces produce no effect whatever, just as if they did not act at all. If the cord is arranged in such a manner that one weight is at the top and the other at the bottom of the scale, and the lower weight be gently set in motion upwards by a slight push of the finger, the motion ought uniformly to continue until this weight has ascended to the top, while simultaneously the other has descended; this would indeed happen if the weights and the wheel could solely obey their inertia, but the unavoidable friction renders the motion gradually slower and brings the whole finally to rest. The resistance of the air to this slow motion is so small that it may be neglected, nor need the small weight of the cord be taken into consideration. To counteract the disturbing influence of friction, a small weight of the form *r*, fig. 43, is used. It is placed

upon the upper one of the two weights P , and is so adjusted as to overcome the resistance of friction ; it produces therefore no motion in the apparatus by its own weight, but maintains against friction any motion produced by a light touch of the finger. This can obviously only be the case if the friction weight is placed upon that weight which is the descending one ; hence we shall always take the weight P on the right hand of the figure as that which descends, and upon which the friction weight is placed. The friction increases if the suspended weights are heavier ; three friction weights will therefore be required, one for the case of 70^{gr} being suspended on each side, a second for $70 + 98 = 168^{\text{gr}}$, and a third for $70 + 98 + 98 = 266^{\text{gr}}$ on each side.

First Experiment.—The brass plate is placed 2 decimetres below the zero of the scale. The two weights of one gramme each are placed upon the left-hand weight, the four grammes weight, besides the friction weight, upon the right-hand weight ; there are thus 72^{gr} on the left, and 74^{gr} on the right side. Raise the upper edge of the right-hand weight to the zero of the scale, after starting the clock or pendulum. By gently pressing with the finger upon the wheel, the apparatus is kept at rest, and started exactly at the beat of the pendulum, taking care not to push the wheel in the act of withdrawing the finger. If the experiment is successful, the extra weight will strike the brass plate precisely two seconds (2^{s}) after starting. A space of 2 decimetres has thus been passed over in 2^{s} , under the action of a force of 2^{gr} . For as there are 72^{gr} on the left side, and 74^{gr} on the right, the moving force is represented by 2^{gr} .

Second Experiment.—To find in what manner the velocity is changed if the force changes, take away one of the grammes on the left, and place it upon the right-hand weight. There are now $70 + 1 = 71^{\text{gr}}$ on the left, and $70 + 4 + 1 = 75^{\text{gr}}$ on the right side. Place the brass plate four decimetres below the starting point and the extra weight will again be heard to strike the plate precisely 2^{s} after starting. In the same time, twice the space has been passed over; the velocity is therefore twice as great as in the last experiment.

Third Experiment.—Remove the remaining gramme weight from the left and place it on the right side. There are now 70^{gr} on the left, and $70 + 4 + 1 + 1 = 76^{\text{gr}}$ on the right; the moving force is 6^{gr} . The space passed over in 2^{s} will be found to be 6 decimetres; that is, the velocity will be three times as great as in the first experiment.

The moved mass was in these three experiments the same, but the moving forces were in the successive experiments in the proportion of $1 : 2 : 3$. The velocities produced were in the same proportion. Hence the law :

The velocities produced by forces of different magnitude acting upon the same mass during equal times, are proportional to these forces; or in other words: The velocities produced are directly proportional to the forces.

In order to observe the effect of the same force upon different masses, we now add weights to each of the 70^{gr} pieces. But here we must consider that not only the weights are set in motion by the moving force, but also the wheel itself; and further, that the motion of the wheel is rotatory, while that of the weights is a motion

of translation. Every part of the weights has at any instant the same velocity as every other; but this is not the case with every part of the wheel; the velocity of the particles at the circumference is greater than that of the others, and it continually diminishes towards the centre which is at rest. It follows from this, that less force is required to give a certain velocity to the circumference of the wheel than would be necessary for giving the same velocity to the whole mass of it. The force actually required is only half of the force which would give the velocity of the circumference to the whole wheel. The weight of the wheel being 100 grammes, the force required is that which would communicate the same velocity to a weight of 50 grammes. In the third experiment the total weight moved by the action of gravity upon the extra weight of 6^{gr} is therefore not only $70 + 76 = 146^{\text{gr}}$, but the wheel must be included and reckoned as a weight of 50^{gr} . The mass moved in this experiment was $50 + 70 + 76 = 196^{\text{gr}}$, the moving force was 6^{gr} , and the space traversed was 6 decimetres in 2 seconds.

Fourth Experiment.—A weight of 98^{gr} is now added at each side. The whole mass moved is $(50 + 70 + 98)$ on the left, $(70 + 98 + 4 + 1 + 1)$ on the right, or 392^{gr} altogether. The moving force is still 6^{gr} , but the mass moved is exactly twice that moved in the third experiment. The plate will now have to be fixed at a distance of three decimetres from the starting point, in order to hear the extra weight strike it after two seconds. Half the space only is now traversed in the same time.

Fifth Experiment.—New weights, again of 98^{gr} each, are added to both sides. The moved mass is now

$392 + 98 + 98 = 588^{\text{gr}}$, or three times that of the third experiment. The plate will now have to be fixed at 2^{decim} distance, in order that the extra weight may strike upon it after the same time. The space is therefore only one third, if the same force has to move three times the mass.

If, as in the third, fourth, and fifth experiments, the same force acts upon different masses, the velocity generated is the smaller the greater the masses moved :

The acquired velocities are inversely proportional to the masses; or, more precisely: The velocities acquired by different masses under the action of equal forces are inversely proportional to the masses.

In the first experiment, the weights of 70 and 76^{gr} , making with the wheel a moved mass of 196^{gr} , pass over a space of 2^{decim} under the action of a force of 2^{gr} ; in the fifth experiment the same space was traversed in the same time by a mass of 588^{gr} acted upon by a force of 6^{gr} . The mass is in the last experiment three times greater than in the first; the moving force is also three times greater; the velocity generated is the same.

Sixth Experiment.—In order to give the velocity of the first experiment to twice the mass, that is, to make it pass over 2^{decim} in 2^{s} , we place on the left side $98 + 70 + 1 = 169^{\text{gr}}$, on the right $98 + 70 + 4 + 1 = 173^{\text{gr}}$. The extra weight is now $173 - 169 = 4^{\text{gr}}$, the moved mass, with the wheel, $173 + 169 + 50 = 392^{\text{gr}}$. Both the moved mass and the moving force are now twice those used in the first experiment. Comparing the results of experiments one, five, and six, we find the law:—

If different masses acquire in equal times equal velocities, the moving forces are proportional to the masses moved.

The wheel of the apparatus is useless unless very accurately turned; the wheel and its frame should therefore be purchased from an instrument maker. The frame is fastened by three wood screws, with round heads, to a vertical surface, as a door-post, or a wall; or it may be screwed to a board, 1^m·6 long, 12^{cm} wide, 2^{cm} thick, into the side of which, at about the height of a table, a strong iron hook is screwed, which serves for clamping the board in a vertical position by the side of the table in the manner shown in fig. 45.

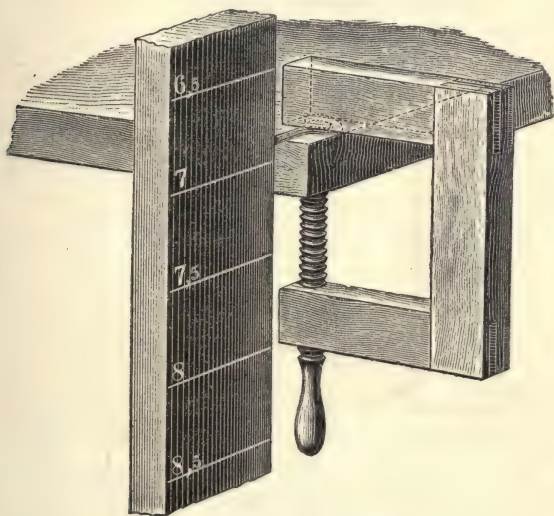
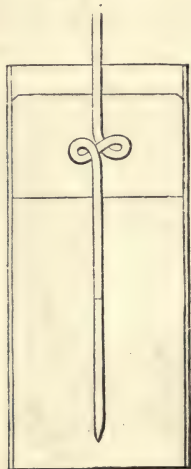


FIG. 45 (*an. proj. real size*).

The board after being screwed perpendicularly to the table may be firmly secured in its position by a small wooden wedge between its lower end and the floor. The divisions may be drawn by means of a common bevel-rule, with strong pencil, either upon the board or the wall itself, or upon a strip of stout drawing-paper, of which the upper end is placed between the frame and the board, and held fast by the frame, while the lower end is fastened by two drawing-pins.

The weights are made of lead, 2^{cm}·5 in diameter. A small hole is bored in the wooden cylinder, round which the paper is rolled, and a brass or copper wire, about 1^{mm} thick, the ends of which are afterwards bent into hooks, is pushed into the hole. To secure it

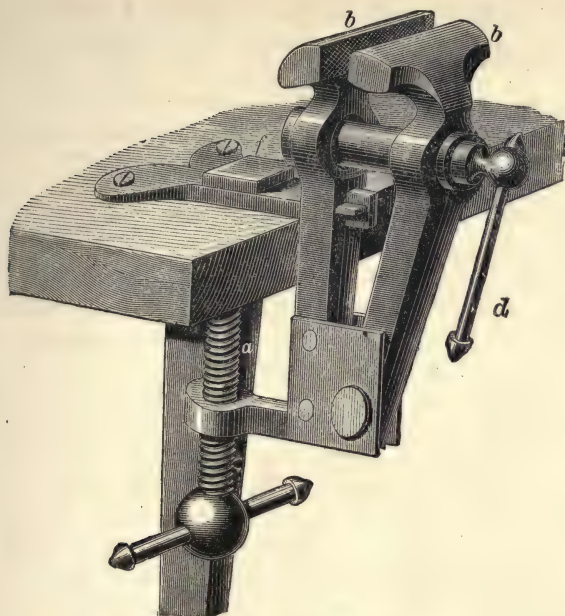
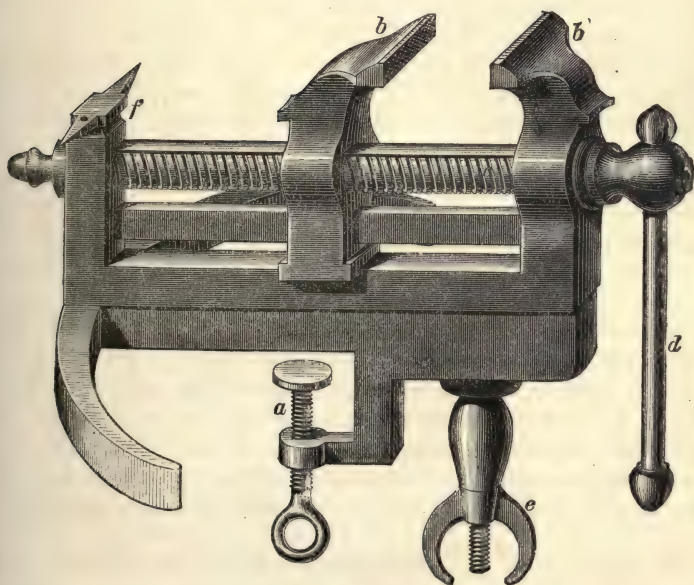
firmly in the lead the form shown in fig. 46 is given to the wire. The 1st and friction weights are cut out of a thin brass plate, the four-gramme weight out of a sheet of zinc. The form shown in *r* and *u* (fig. 43) is given to these weights in the following manner: The weights are placed upon a piece of lead, and by means of a punch (fig. 47), a hole is punched in the middle of each; two parallel cuts are now made from the side to the hole, the whole hammered flat, and accurately adjusted to the proper weight by filing. Thin sheets of metal may be cut by a pair of common strong

FIG. 46 (*real size*).FIG. 47 ($\frac{1}{2}$ *real size*).

scissors, but it is better to use for the purpose a pair of small shears, of which one jaw is clamped horizontally between a vice. A small vice is indispensable, at least one of the kind represented in fig. 48, but much more servicable is the parallel vice (fig. 49). The vice is secured to the corner of a very firm table or bench by the screw *a*; the handle *d* is used for turning the screw *c*, and clamping any objects between the cheeks *b b*.

The upper part of the vice may be loosened by turning the winged screw *e*, and clamped again in any required position; this is very convenient for many purposes, and almost indispensable if the vice cannot be attached to a corner which is perfectly accessible all round. The small anvil carries projecting 'horns' for hammering wires or plates of metal either round or into angles.

The cord should be of twisted silk, and so long that one weight is close to the wheel when the other touches the floor. In

FIG. 48 (an. proj. $\frac{2}{3}$ real size).FIG. 49 ($\frac{1}{2}$ real size).

experimenting, however, the weights should not be allowed to come in actual contact with the floor, for this would bend the hooks or even break them off. A small box filled with sawdust placed upon the spot which the descending weight would touch will protect it against damage, in case the timely stopping of it should have been forgotten.

The pendulum consists of a disc of lead, about 1^{kg} in weight, suspended by a fine silken cord. Procure from the turner a wooden disc, from 6 to 8^{cm} in diameter, and about 2^{cm} thick; make in it a small hole, but not quite through, and insert into it a wire as in fig. 46, surround the disc with paper, place it as horizontal as possible, and pour into it about 1^{kg} of lead, rather more than less. The lower piece of wire which projects is turned into a small ring, which is close to the disc, the upper wire is allowed to project a few centimetres, made quite straight and perpendicular to the disc, and a small hook is bent at its extremity. The small weight is made of a flat piece of brass or copper, about 1^{cm} in diameter and 0^{mm}·5 thick, to the middle of which a small wire ring is soldered. The small weight must be perfectly horizontal when suspended by the thread, so as to lie quite flat upon its support (fig. 44), for which a china plate may be used. The thread which carries the leaden disc should be so long that the whole of its length measured from the point of suspension, that is, from the lower edge of the arms of the retort-stand which holds it, together with the length of the projecting wire, and half the thickness of the leaden disc, should be 99^{cm}. The distance should of course be measured while the disc is suspended and the thread stretched by its weight. The fine thread for the small weight is made just so long as to allow the weight to rest upon the plate when the pendulum is at rest; the small glass tube through which the thread passes should be about 2^{mm} wide, with rounded edges, to prevent the thread from being cut. In using the pendulum the heavy weight is moved aside from its position of equilibrium until the small weight is raised not quite so high as the glass tube, and is then let go. If the above instructions for adjusting the weights and distances have been strictly carried out, the pendulum will beat seconds, with an exactness quite sufficient for our purpose; it will not vibrate very long but quite long enough for one experiment, and may be started again for the next one. A pendulum properly constructed for precisely beating seconds and going for some time is expensive, and not necessary for our experiments.

10. *Motion of Falling Bodies.*—Bodies allowed to fall from different heights acquire different velocities.

A piece of paper, or a feather, falls more slowly than a piece of lead or wood, and if the height is considerable we shall moreover find that the lead reaches the ground sooner than the piece of wood. This difference in the velocity of falling bodies is due to the resistance of the air; the force of gravity does not act differently on different bodies, but acts equally upon all kinds of matter. A body of small specific gravity, or generally every body which possesses a large external surface in proportion to its mass, meets with a greater resistance by the air of our atmosphere, and falls therefore more slowly than a body of greater specific weight and smaller surface. Glass cylinders have been used for experiments on falling bodies of various kinds, and it has been found that when the air, and hence its resistance, was removed, all bodies, whether small or large and whatever their specific gravity, fall with equal velocity.

Cut a round disc of thin paper, a few millimetres smaller than a crown piece or a bronze penny, and place the paper disc upon the coin. Hold the coin perfectly horizontal with the thumb and forefinger at opposite points of the edge, about 0.^m5 above the table and let it fall. The paper disc will not fall behind, but will reach the table together with the coin, for the latter pushes the air aside, and the paper disc is unresisted in its fall. The velocity of bodies which fall freely is so great that the motion can only be observed with some difficulty, but its laws may be studied conveniently by means of the machine described in the preceding article. The descent of the weight is slower, but it is regulated by

the same law as would determine its motion if it were falling freely.

The law which has been derived from the first, fifth, and sixth experiments, was that different masses move with the same velocity, if the forces which act upon them are proportional to the masses. Now all bodies fall with equal velocity, if unresisted by the air. It follows from this that the force with which gravity acts upon different masses must be proportional to these masses. A mass, for instance, which is six times as great as another mass, is attracted by the earth with six times the force which acts upon the smaller mass. A body once in motion maintains, by its inertia, the acquired velocity unaltered, if not acted upon by any force, and if it has not to overcome any resistance; it passes over equal spaces in equal consecutive times; it has a *uniform motion*. But if constantly acted upon by a force which impels the body more and more, its velocity will continually increase; such a body has an *accelerated motion*. If a force, as is the case with the force of gravity, has constantly the same effect upon a body, its velocity will continually increase by the same quantity, and the motion is in that case uniformly accelerated. When we have on the left side of the machine $70 + 98 + 98 = 266^{\text{gr}}$, on the right, $70 + 98 + 98 + 4 + 1 + 1 = 272^{\text{gr}}$, or, with the wheel, altogether 588^{gr} , moved by a force of 6^{gr} , the velocity increases in every second by one decimetre; for at the commencement it is zero, and after 1^{s} it will be 1^{decim} , after 2^{s} it will be 2^{decim} , etc. But the space traversed in the first second is not 1^{decim} , nor is it in the second 2^{decim} , etc., for the weight has not a velocity of 1^{decim}

during the whole of the first second, but does not acquire this velocity until the end of it. The weight had no velocity at the beginning of the first second, but it increases its velocity uniformly during the second, and it is 1^{decim} at the end of this time; the weight will therefore pass over the same space which it would have traversed had it moved with a mean velocity of $0^{\text{decim}} \cdot 5$, this being the mean of 0 and 1; the weight will hence pass over $0^{\text{decim}} \cdot 5$ in the first second. At the end of the first second, or, what is the same, at the beginning of the second second, the velocity of the weight is 1^{decim} , at the end of the second second 2^{decim} , the mean velocity during the second second is therefore $1^{\text{decim}} \cdot 5$, and this is also the space passed over during the second second. If this calculation were continued in the same manner, we should obtain the following table:—

I. Successive Seconds.	II. Initial Velocity.	III. Final Velocity.	IV. Mean Velocity, or space passed over in each Second.	V. Total space passed over from commencement of motion.
1st	0	1	$\frac{0+1}{2} = 0\cdot5$	$0\cdot5 \quad . \quad . \quad . \quad = 0\cdot5 = 1 \times 1 \times 0\cdot5$
2nd	1	2	$\frac{1+2}{2} = 1\cdot5$	$0\cdot5 + 1\cdot5 \quad . \quad . \quad . \quad = 2\cdot0 = 2 \times 2 \times 0\cdot5$
3rd	2	3	$\frac{2+3}{2} = 2\cdot5$	$0\cdot5 + 1\cdot5 + 2\cdot5 \quad . \quad . \quad = 4\cdot5 = 3 \times 3 \times 0\cdot5$
4th	3	4	$\frac{3+4}{2} = 3\cdot5$	$0\cdot5 + 1\cdot5 + 2\cdot5 + 3\cdot5 \quad . \quad = 8\cdot0 = 4 \times 4 \times 0\cdot5$
5th	4	5	$\frac{4+5}{2} = 4\cdot5$	$0\cdot5 + 1\cdot5 + 2\cdot5 + 3\cdot5 + 4\cdot5 = 12\cdot5 = 5 \times 5 \times 0\cdot5$

The length of the whole space passed over during a certain time is found by summing the spaces traversed in the single seconds: this is done in column V, but it

is also shown in that column that the space may be found more simply by multiplying the number of seconds during which the body has been in motion by itself and by 0·5, that is by the space passed over during the first second, or by half the increase of velocity in each second. The product of a number multiplied by itself is the *square* of that number, thus 25 is the square of 5; again, the increase of velocity in each second, if the motion is uniformly accelerated, is briefly called the *acceleration*: the above fact may therefore be stated thus:

The magnitude of the space traversed by a uniformly accelerated body during a given time from the beginning of the motion is found by multiplying half the acceleration by the square of the time.

Thus in 7 seconds the space traversed by the weight would be $7 \times 7 \times 0\cdot5 = 24\cdot\text{decim}5$. If the perforated brass plate, after the weights specified in the beginning of this article have been attached, be fixed at the foot of the scale, it will be found that the weight passes exactly opposite to the divisions corresponding to 0·5, 2, 4·5, 8, 12·5 decimetres after 1, 2, 3, 4, 5 seconds respectively, provided that the motion commenced exactly at the beat of the pendulum. That the numbers given in the table represent the correct velocities acquired at the end of the first, second, etc. second may be tested thus: the perforated brass plate is successively suspended opposite to the division at which the descending weight arrives after 1, 2, etc. seconds. The extra weight sets the whole into uniformly accelerated motion; but when the descending weight passes through the brass plate, the extra weight is retained upon it, and

the force which causes the acceleration ceases to act. The weights move now solely in virtue of their inertia, the velocity ceases to increase, and the spaces now traversed show what velocity has been acquired. When the plate is opposite to 0·5, and the extra weight thus ceases to act at the end of the first second, the descending weight will arrive at the end of the next second at 1·5, at the following at 2·5, and so on; a velocity of 1^{decim} is hence acquired during the first second. When the plate is opposite to 2·0, and the extra weight is thus removed after 2 seconds, the descending weight will arrive at 4, 6, 8, etc. at the end of the third, fourth, fifth, etc. second. When the plate is opposite to 4·5, the descending weight will arrive at the end of the next three seconds respectively opposite to 7·5, 10·5, 13·5; when the extra weight is stopped at 8·0 on the scale, the descending weight will move in the next second to 12·0, and so on.

The results calculated in the above table may be tested in this manner by observation. Care must be taken that the thread passes exactly through the middle of the holes in the extra weights, otherwise friction will be produced; if possible a single extra weight of 6^{gr} should be used, but this is not absolutely necessary. The velocity after the first second is rather small, and a small inaccuracy in fixing the plate for the reception of the extra weight may cause perceptible differences in the velocity of the descending weight from the expected result; the experiments are from this cause more successful for the velocities obtained after two, three, etc. seconds.

The circumstances which accompany the free fall of

a body are, as has been already stated, perfectly similar to those now discussed, but the acceleration is much greater. Our mass, weighing 588^{gr} , was acted on by a force represented by 6^{gr} ; but if we allow the same mass to fall freely, so that no other mass is set in motion by it, the force which acts upon it is $588 = 6 \times 98^{\text{gr}}$. Now it has been shown that the velocities acquired in equal times, or in other words the accelerations, are proportional to the forces. A force 98 times greater will hence produce an acceleration 98 times greater; the freely falling body would have therefore an acceleration of $98 \times 1^{\text{decim}} = 9^{\text{m}}\cdot 8$; and since all bodies which have not to overcome the resistance of the air fall with equal velocity, it follows generally that $9^{\text{m}}\cdot 8$ is the acceleration which the force of gravity imparts to falling bodies: this is the *acceleration of gravity*. It is hence possible to calculate for a small body which possesses great weight but a small surface, such as a leaden bullet or a stone, the space traversed in a given time. Thus if a stone dropped from a tower reaches the ground in 2.5 seconds, the height of the tower is equal to the square of the time multiplied by half the acceleration of gravity, or $= 2.5 \times 2.5 \times \frac{9^{\text{m}}\cdot 8}{2} = 30^{\text{m}}\cdot 625$.

The velocities acquired by a freely falling body and the spaces traversed for the first 6 seconds are given in the following little table:

	Velocity acquired.	Whole space traversed.
At the end of 1st second	$1 \times 9.8 = 9^{\text{m}}\cdot 8$	$1 \times 4.9 = 4^{\text{m}}\cdot 9$
" " 2nd "	$2 \times 9.8 = 19.6$	$4 \times 4.9 = 19.6$
" " 3rd "	$3 \times 9.8 = 29.4$	$9 \times 4.9 = 44.1$
" " 4th "	$4 \times 9.8 = 39.2$	$16 \times 4.9 = 78.4$
" " 5th "	$5 \times 9.8 = 49.0$	$25 \times 4.9 = 122.5$
" " 6th "	$6 \times 9.8 = 58.8$	$36 \times 4.9 = 176.4$

11. *Motion of Projectiles.*—When a body, capable of moving freely in every direction, is acted on by several forces at the same time, each force will produce precisely the same effect as if it acted alone. If a body is thrown from the hand, it maintains the velocity hereby acquired, by its inertia, but is at the same time acted on by gravity. A stone thrown vertically downwards from a tower with a velocity of 10^m per second, would pass in one second through 10^m , in two seconds through 20^m , etc., if there were no force of gravity. But, as has been shown in the preceding article, gravity causes the body to move downwards in one second through $4^m\cdot9$, in two seconds through $19^m\cdot6$, etc. The body will hence move in the first second through $10 + 4^m\cdot9 = 14^m\cdot9$, in two seconds through $20 + 19\cdot6 = 39^m\cdot6$, in three seconds through $30 + 44\cdot1 = 74^m\cdot1$, 30^m being due to the force with which the body has been projected, and $44^m\cdot1$ to the force of gravity.

The velocity of a falling body increases in every second by $9^m\cdot8$. If the velocity of the stone when it leaves the hand be 10^m , it will be at the end of the first second $10 + 9\cdot8 = 19^m\cdot8$; at the end of the second second it will be $10 + 2 \times 9\cdot8 = 29^m\cdot6$, and at the end of the third second $10 + 3 \times 9\cdot8 = 39^m\cdot4$. The average velocity with which the body moves in the first second is the arithmetical mean of 10 and $19\cdot8$, viz., $\frac{10 + 19\cdot8}{2} = 14^m\cdot9$; the average velocity of the second second is the mean of $19\cdot8$ and $29\cdot6$, viz., $\frac{19\cdot8 + 29\cdot6}{2} = 24^m\cdot7$; the average velocity during the third second is similarly the mean of $29\cdot6$, which is the velocity at the end of the second second, or beginning of

the third, and 39·4, which is the velocity at the end of the third second; hence it is $\frac{29\cdot6 + 39\cdot4}{2} = 34^{\text{m}}\cdot5$.

The spaces passed over in each second are obviously equal to the average velocities in each second, and the total space traversed in two or more seconds is found by adding together the spaces traversed in the separate seconds. Thus we find the space traversed in two seconds to be $14\cdot9 + 24\cdot7 = 39^{\text{m}}\cdot6$, in three seconds $39\cdot6 + 34\cdot5 = 74^{\text{m}}\cdot1$, numbers which agree with those above found by a different reasoning.

If a body be thrown vertically upwards, the force of gravity will diminish its velocity by the same amount as that by which it was increased when it was projected downwards. If we suppose a body to be thrown upwards with a velocity of $29^{\text{m}}\cdot4$, it will after one second have a velocity of only $29\cdot4 - 9\cdot8 = 19^{\text{m}}\cdot6$, after two seconds of $19\cdot6 - 9\cdot8 = 9^{\text{m}}\cdot8$, and at the end of the third second its velocity is completely destroyed; the body will at this instant cease to move upwards and will begin to fall; it has reached the greatest height to which it can ascend. The velocity of a body projected vertically upwards is thus diminished by $9^{\text{m}}\cdot8$ in every second, and the time which elapses after the beginning of the upward motion until it ceases is hence easily found by calculating how many times $9\cdot8$ is contained in the initial velocity; or, in other words, *the time required by a body projected vertically upwards for reaching the highest point is found by dividing the velocity of projection by the acceleration of gravity.* The time of ascent for a velocity of projection of 98^{m} is thus found to be $\frac{98}{9\cdot8} = 10$ seconds; for a velocity of $12^{\text{m}}\cdot25$ it is

$\frac{12.25}{9.8} = 1.25$ seconds. The time of the ascent being

known, the height which the body attains may be calculated. The space which a body projected upwards describes is diminished by gravity in the same manner as that in which the same force increases the space traversed by a body projected downwards. If the body is projected with a velocity of $29^m.4$, its height after three seconds would be $3 \times 29^m.4 = 88^m.2$, if there were no gravity. But gravity moves the body downwards in three seconds through $3 \times 3 \times 4.9 = 44^m.1$, and the attained height is therefore only $88.2 - 44.1 = 44^m.1$.

In this manner the heights may be calculated which correspond to different velocities of projection. The following small table exhibits a few values which are connected in this manner, and in column 5 is shown a more simple method of calculating the heights.

1.	2.	3.	4.	5.
Velocity of projection.	Time required for attaining the greatest height.	Space which would be described by the body if gravity were not acting.	Space through which the body is moved downwards by gravity.	Greatest Height actually attained by the body.
$9^m.8$	$\frac{9.8}{9.8} = 1^s$	$1 \times 9.8 = 9^m.8$	$4^m.9$	$9.8 - 4.9 = 4^m.9 = \frac{9.8 \times 9.8}{19.6}$
$19^m.6$	$\frac{19.6}{9.8} = 2^s$	$2 \times 19.6 = 39^m.2$	$19^m.6$	$39.2 - 19.6 = 19^m.6 = \frac{19.6 \times 19.6}{19.6}$
$29^m.4$	$\frac{29.4}{9.8} = 3^s$	$3 \times 29.4 = 88^m.2$	$44^m.1$	$88.2 - 44.1 = 44^m.1 = \frac{29.4 \times 29.4}{19.6}$
$39^m.2$	$\frac{39.2}{9.8} = 4^s$	$4 \times 39.2 = 156^m.8$	$78^m.4$	$156.8 - 78.4 = 78^m.4 = \frac{39.2 \times 39.2}{19.6}$
$49^m.0$	$\frac{49.0}{9.8} = 5^s$	$5 \times 49.0 = 245^m.0$	$122^m.5$	$245.0 - 122.5 = 122^m.5 = \frac{49.0 \times 49.0}{19.6}$
$58^m.8$	$\frac{58.8}{9.8} = 6^s$	$6 \times 58.8 = 352^m.8$	$176^m.4$	$352.8 - 176.4 = 176^m.4 = \frac{58.8 \times 58.8}{19.6}$

It appears from column 5 that *the height of ascent is found by multiplying the velocity of projection by itself, and dividing the resulting square number by twice the acceleration of gravity* ($2 \times 9.8 = 19.6$). The truth of this rule is easily seen. By dividing the velocity of projection by the acceleration the time of ascent is found, and this time must again be multiplied by the velocity of projection, in order to find the height which the body would reach if it were uninfluenced by gravity; hence instead of first dividing the velocity of projection by the acceleration, and multiplying the quotient again by the velocity of projection, the velocity of projection may be at once multiplied by itself and divided by the acceleration. But the height thus found is, as appears from a comparison of columns 3, 4, and 5, always twice as great as that actually reached, hence it follows that the actual height is equal to the square of the velocity divided by twice the acceleration. If this table be compared with the two small tables given at the end of the last paragraph, further simple relations will appear. For instance, a body falls in six seconds through a space of $176^{\text{m}}.4$ and acquires a velocity of $58^{\text{m}}.8$; conversely, a body projected with a velocity of $58^{\text{m}}.8$ ascends for six seconds and reaches a height of $176^{\text{m}}.4$; and the same relation holds for any other velocity of projection. *The velocity which a body acquires in falling through a certain height is always equal to the velocity with which the body must be projected upwards in order to reach the same height.* A body projected upwards and having reached the greatest height is then for an instant at rest, after which it begins again to fall freely; it follows *that a body ac-*

quires when returning to its starting-point the same velocity as that with which it was projected. The time required for the ascent is hence equal to that of the descent to the point of starting.

The laws which regulate the motion of bodies projected vertically upwards or downwards retain essentially their application to bodies projected laterally, either in a horizontal or oblique direction. But the path of a body laterally projected is not a straight line; it is a curve called a *parabola*. A body projected hori-

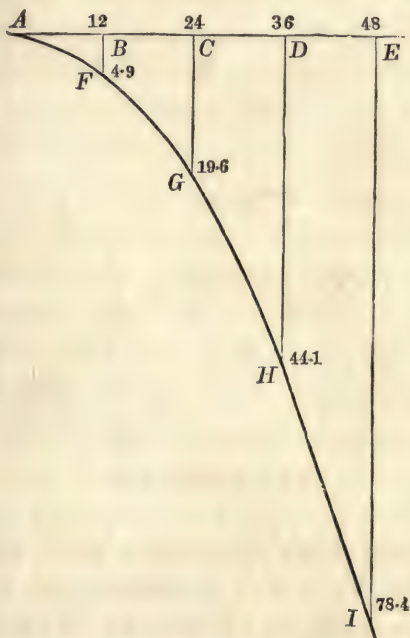


FIG. 50 ($\frac{1}{1000}$ real size).

izontally would continue its motion in this direction, if gravity did not act upon it, and its velocity would also in that case remain uniform. The horizontal motion is

not affected by the force of gravity ; but this force causes the body, while moving horizontally, to move downwards at the same time with continually increasing velocity. In fig. 50 is represented the actual path, reduced to $\frac{1}{1000}$ th of its real magnitude, of a body which has been projected horizontally with a velocity of

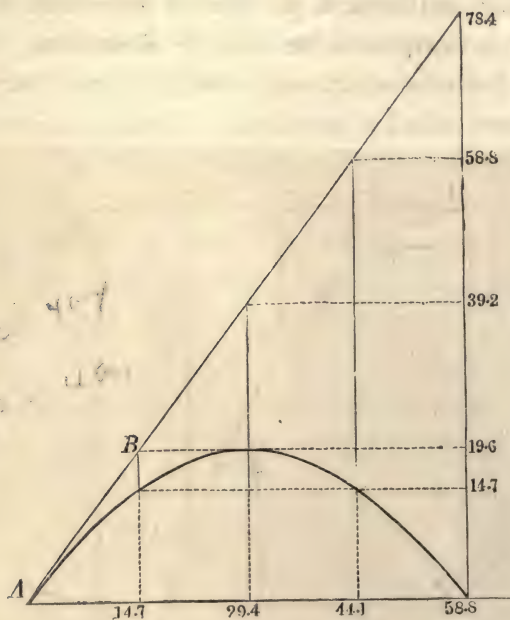


FIG. 51 ($\frac{1}{1000}$ real size).

12^m. The body would thus move horizontally through 12, 24, 36, 48^m in 1, 2, 3, 4 seconds, and arrive at the ends of these intervals of time at *B*, *C*, *D*, *E* respectively. But gravity causes the body during these intervals also to move downwards through 4^m·9, 19^m·6, 44^m·1, 78^m·4, so that the body actually arrives at *F*, *G*, *H*, *I* at the end of the successive seconds. Fig. 51 represents on the same scale the path of a body pro-

jected obliquely upwards in the direction $A B$ with a velocity of $24^m \cdot 5$. A motion of $24^m \cdot 5$ in this direction makes the body rise vertically upwards through $19^m \cdot 6$, and move in the same time horizontally through $14^m \cdot 7$. The horizontal motion is uninfluenced by gravity, and the body moves in each second laterally through $14^m \cdot 7$. But the heights to which the body would ascend by the velocity of projection after 1, 2, 3, 4 seconds are diminished by the spaces through which the body would fall

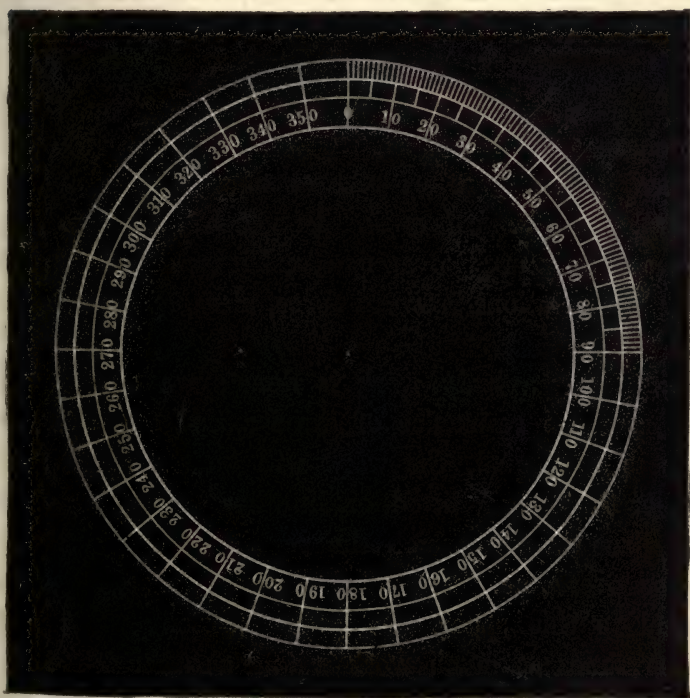


FIG. 52.

in these times by the action of gravity ; the successive heights are therefore really :—

After 1 second ($1 \times 19.6 = 19.6$) — $4.9 = 14^m.7$.

After 2 seconds ($2 \times 19.6 = 39.2$) — $19.6 = 19^m.6$.

After 3 seconds ($3 \times 19.6 = 58.8$) — $44.1 = 14^m.7$.

After 4 seconds ($4 \times 19.6 = 78.4$) — $78.4 = 0^m.7$.

The direction AB is inclined to the horizontal direction at an angle of 53.13 degrees (53.13). The whole circumference is divided into 360 equal parts, which are called *degrees*; the symbol $^\circ$ placed at the top and to the right of the number of degrees in an angle is used as an abbreviation for this word. A right angle contains 90° . An angle of 45° is half of a right angle, an angle of 30° a third, etc. In Fig. 52 one right angle is divided into degrees, the remaining portion of the circumference into parts of 10 degrees each. Acute angles are those between 0° and 90° ; obtuse angles are those between 90° and 180° .

12. *Mechanical Work*.—The expenditure of force, which, as has been explained in Art. 8, is required for changing the state of rest or of motion of a body, is called *mechanical work*. In general, work is done when a resistance is overcome, and it remains to investigate the relations between force, mass, space, velocity, and work.

In lifting a body work is done; we overcome in this case the resistance of gravity. If other circumstances are equal, the work will be the greater the higher the body is lifted, or, in other words, the greater the space through which the resistance of gravity has to be overcome. The work done is directly proportional to this space. In lifting a body through 3^m three times as much work is done as when it is raised 1^m , and five times as much work will have to be done to lift it through 15^m as is required for 3^m . The work, however, does not only depend upon the space alone, but also upon the magnitude of the resistance which is to be overcome. To move a ball upon a very smooth

horizontal table requires very little work, because the resistance is small. To move the same ball upon a very rough surface requires more work, because the resistance of friction is greater. To raise the ball from the table requires still more work, for in this case the resistance of gravity has to be overcome. The work done in moving a body through a certain space is jointly proportional to this space and to the force or resistance overcome; or, in other words, it is the product of these two quantities. The work required to lift a body which weighs 5^{kgr} through 3^{m} is $3 \times 5 = 15$ times as great as the work required to lift 1^{kgr} through 1^{m} . The work necessary to overcome the resistance of 1^{kgr} through 1^{m} is the unit used for computing work, and is called the *Kilogrammetre*, or *Metre-kilogramme*. The work which we perform when we raise a body is not lost; it reappears when we leave the body to itself. It is again drawn downwards by gravity and acquires a certain velocity. The work now done by gravity consists in overcoming the inertia of the body; for the body which was at rest begins to move with increasing velocity. In the moving body the work done by gravity is accumulated; it acquires, by virtue of its velocity, the capacity of itself doing work, of overcoming any other resistance. A stone raised and allowed to fall upon a peg or stake on the ground, drives the peg or stake some distance into the soil, and thus overcomes the resistance which the soil offers to these bodies.

We know from the preceding article that the velocity acquired by a body in falling from a certain height is equal to the velocity with which a body must be thrown upwards to make it rise to the same height. With

reference to mechanical work, this fact may be thus stated:—*The quantity of work which a falling body contains is exactly the same as that which would be sufficient to raise it to its original height.*

It is somewhat difficult to prove this fact experimentally in the case of bodies falling freely; but it may be more easily demonstrated by means of bodies which are allowed to descend by the force of gravity along a path which is not vertical, provided that friction and other resistances to the motion are so small that the work expended in overcoming them may be left out of consideration. A body suspended by a fine thread may be constrained to move along the arc of a circle, and this circular motion is very convenient for illustrating the above statement.

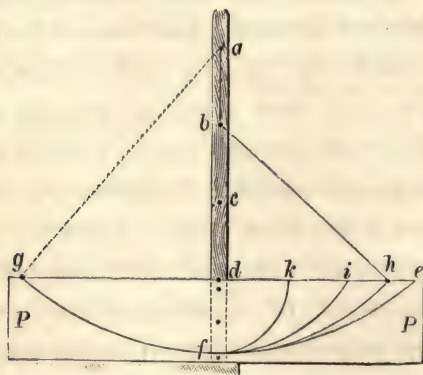


FIG. 53 ($\frac{1}{10}$ real size).

Remove the clamp from a retort-stand and attach to it, with a few tacks or drawing-pins, a rectangular piece of cardboard, PP' , fig. 53, about 55^{cm} long, and 11^{cm} high, having previously made four horizontal holes, a, b, c, d , in the vertical rod of the stand, at distances of 41, 31, 21, 11^{cm} respectively from the foot. Pass a long pin of iron wire, sufficiently thick to fit tightly, through the uppermost hole, and let the head project about 1 or 1^{cm}.5 from the rod;

tie a piece of thread to the head of the pin, and wind the other extremity round a lead pencil close to the pointed end, making the distance between the pin a and the point of the pencil 40^{cm} . Now describe the arc efg with the point of the pencil. Next insert successively an easily fitting pin into the holes b, c, d , and describe the arcs fh, fi, fk , by placing the thread which remains fixed at a upon the left side of the pin, so that it successively assumes the positions abh, aci, adk . The pencil must always be kept horizontal and perpendicular to the plane of the cardboard. The pencilled arcs may then be carefully drawn in ink, using the latter sparingly if the cardboard is apt to make the ink run. The pencil is now replaced by a small but heavy weight, best by a leaden bullet with a small hook attached. The end of a piece of wire 3^{cm} long and 1^{mm} thick is somewhat bent and introduced by that end into a bullet mould, the other end slightly projecting from the mould. Lead being poured in, the whole is allowed to cool, and the superfluous lead round the wire carefully cut away, so as not to cut the wire itself, which is then bent into a little hook. The bent end of the wire must be made larger than the aperture of the mould; otherwise it would be pushed out by the lead which is poured into the mould, because iron, and also copper and brass, swim upon liquid lead. This precaution is of course unnecessary if the wire be held firmly in the mould while the lead is being poured in. After the bullet is tied to the thread, its centre should be exactly opposite to the point f , when the thread hangs vertically.

The moveable pin being removed, the bullet is raised to e , and allowed to fall. Drawn downwards by gravity, but unable to fall perpendicularly, it is forced by the thread to describe the arc ef . The velocity acquired is just sufficient to move the bullet on the other side upwards to g , or, more precisely, nearly to g ; because a small amount of work is expended in overcoming the resistance of the air and the stiffness of the thread. Further, if the moveable pin is again inserted into b , the thread placed upon the left side of it, and the bullet as shown in the figure brought to h , the arc hf will be described by the bullet if left to itself. The

velocity acquired in moving through this space is precisely the same as that acquired through the space ef . This is shown by the fact that the bullet rises again to g on the left side. Precisely the same happens if the tack is placed at c or d , and the bullet constrained to move through the arcs if , or kf ; it will always rise on the left side to g . Conversely, if the bullet be brought by the hand to g , and allowed to fall, it will move to e , if the moveable pin is removed; but if the latter is placed at b , the thread will be arrested by it when the bullet arrives at f , and the bullet moves to h . If the tack is at c or d , the bullet describes similarly the arcs gfi , or gfk .

The law here observed with reference to circular arcs of various forms holds generally with reference to all kinds of spaces traversed. / *The velocity acquired by a body which moves under the influence of gravity is independent of the form of the path traversed. It is solely dependent upon the vertical height of the space through which the body has passed.* / What is said here of the velocity is also applicable to the accumulated work. A body of 6^{kg} which has fallen from a height of 10^{m} contains $6 \times 10 = 60$ kilogrammetres of work; for the velocity acquired is precisely sufficient to raise the body, that is a weight of 6^{kg} , again through a space of 10^{m} . Hence the work accumulated in a body which has been set in motion by gravity is found by multiplying the attractive force which draws it downwards into the perpendicular height through which it has fallen. The attractive force is in most cases nothing but the weight of the body. It is always the weight, if the whole body moves under the action of gravity. The case is, how-

ever, somewhat different in the experiments made with the machine for demonstrating the motion of falling bodies. The wheel and weights were not moved by their whole weight, but by the extra weight placed to the right. In the first experiment (page 51), we had on the left side 72^{gr} , on the right 74^{gr} , that is an extra weight of 2^{gr} or $0^{\text{mgr}}\cdot002$. The weight of 2 grammes acts through a perpendicular distance of 2 decimetres or $0^{\text{m}}\cdot2$. The accumulated work is, therefore, $0\cdot002 \times 0\cdot2 = 0\cdot0004$ kilogrammetres. This can be proved by observing the motion which takes place after the extra weight has struck upon the perforated plate. A weight of 4^{gr} is thus removed on the right side, and there is now an extra weight of 2^{gr} on the left side; nevertheless, the weight on the right side continues to descend through a further space of nearly 2 decimetres. By the work accumulated in the moving mass (wheel and weights), a weight of $0^{\text{mgr}}\cdot002$ is raised through nearly $0^{\text{m}}\cdot2$, that is, work is done amounting nearly to $0\cdot0004$ kilogrammetres. The reason why the work done is not exactly $0\cdot0004$ kilogrammetres is that a weight of 4^{gr} was retained upon the plate, and the accumulated work of the remainder only could be used for doing work.

The height to which a body rises, if projected with a given velocity, or, as it is called, 'the height due to velocity,' is, as shown in the preceding article, found by dividing the square of the velocity by twice the acceleration of gravity. A moving body is capable of raising its own weight to this height; that is, it is capable of doing an amount of work which is equal to the product of its weight into the height due to its velocity. It follows that:—

The work accumulated in a moving body is found by multiplying its weight into the square of its velocity, and dividing the product by twice the acceleration of gravity.

For instance, the work accumulated in a body which weighs 5^{kg}, and has a velocity of 12^m, is $\frac{5 \times 12 \times 12}{19.6}$

= 36.73 kilogrammetres. In order to test the agreement of this rule with the previous example we must consider, 1st. That the velocity acquired by the falling weight in the first experiment is the same as that acquired in the experiments of Article 10; for in the first experiment the moving mass is one-third of that in the experiments made on falling bodies; but the moving force (the extra weight) is in the first experiment one-third of the moving force in the latter experiment; the acceleration is therefore the same in both. 2ndly. That the wheel must be considered as a weight of 50^{gr}, and that hence the whole moving mass amounts to $50 + 72 + 74 = 196^{\text{gr}} = 0^{\text{kg}}.196$. The velocity obtained after passing over a space of 2^{decim} is, in the first experiment, as well as in those of Article 10, 2 decimetres or 0^m.2; the accumulated work is, therefore, $\frac{0.196 \times 0.2 \times 0.2}{19.6} = 0.0004$ kilogrammetres.

13. *Simple Machines.* — Work applied in any form may be converted into another form in various ways. It requires a definite though small amount of work to push a needle through a piece of cloth. We know that the work required is equal to the product of the expended force, that is, the pressure upon the needle, into the space through which the needle has moved. To drive

a nail into a board or a beam requires far more work. The force necessary to drive the nail into the wood may, in the case of a nail of average size, be taken as 100^{kgr} ; if the depth to which the nail is to be driven in is 4^{cm} ($= 0^{\text{m}}\cdot 04$), the work required is $100 \times 0\cdot 04 = 4$ kilogrammetres. This work cannot be performed by the hand alone, because it is incapable of exerting a pressure of 100^{kgr} . We use for this reason a hammer, to which the muscular force of the arm gives a certain velocity, that is a certain amount of accumulated work. If the blows were delivered at a distance of $0^{\text{m}}\cdot 25$, with a force of 2^{kgr} , the accumulated work would be $2 \times 0\cdot 25 = 0\cdot 5$ kilogrammetres, when the hammer reaches the nail. The nail prevents the onward motion of the hammer, and the work is now expended in overcoming the resistance of the wood. Each blow does $0\cdot 5$ kilogrammetres of work; hence eight blows will be required to drive the nail to the required depth.

In a similar manner many cases occur in which work to be performed can only be done with the help of certain auxiliary contrivances. These are called *simple machines*, or *mechanical powers*; and their function is to convert one form of work into another form. None of these machines can generate work, nor increase it; on the contrary, they all involve a certain loss of work, which is expended in overcoming the resistance which the force of friction opposes to their motion. The advantage of a machine consists in the conversion of work which is given in an unavailable form into an available form.

An example of such a simple machine is the *Wheel and Axle*, essentially a combination of inseparably con-

nected cylinders, moveable about a common axis. Such a combination, consisting of 3 wooden cylinders of 6, 4, and 2^{cm} diameter, moveable round an axis of metal, may be inserted into the frame used for the experiments on falling bodies, as shown in Fig. 54. A small pin, as seen at *a*, is fixed at any point of the circumference, and a cord is fastened to it. A weight *G*, attached to the end of a cord wound round the smallest cylinder, may be raised by pulling a cord which passes in an opposite direction round one of the larger cylinders. When *G* rises, a greater length of cord will clearly be

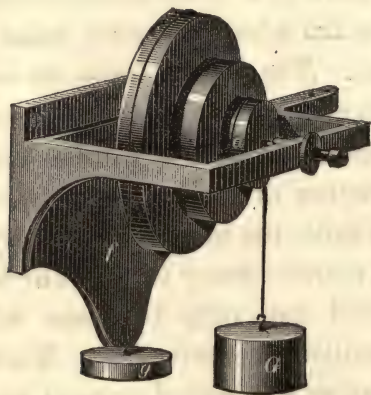


FIG. 54 (*an. proj.* $\frac{1}{2}$ *nat. size*).

wound off the larger cylinder (usually called the *wheel*) than is wrapped round the smaller cylinder (usually called the *axle*); in the case represented in the figure, the wheel is three times as great as the axle, and hence the length of cord unwrapped will be three times as great as the length wrapped on. If *G* weighs 0^{kgr}·3, and it is required to raise it 0^m·1, the work necessary is $0\cdot3 \times 0\cdot1 = 0\cdot03$ kilogrammetres. If we pull the cord *f*, of which 0^m·3 will have to be wound off, we shall have

to apply a force of $\frac{0.03}{0.3} = 0^{\text{kgr}}.1$, for the work done by this force must be equal to the work done in raising G , and since work = force \times space, we can conversely find the force by dividing the work by the space, in this case by dividing 0.03 kilogrammetres by $0^{\text{m}}.3$.

Instead of pulling the cord by the hand, the necessary work may be done by a descending weight. This weight, g , must in our case be $0^{\text{kgr}}.1$. In general, if the wheel is three times as large as the axle, the weight to be suspended from it must be one-third of the weight to be raised by the axle. If the weights are correctly suspended, the wheel and axle will be at rest, but a small force will be sufficient to set it in motion. This force is solely applied to overcome the resistance of friction. The work of raising one of the weights is entirely performed by the other which descends.

If the weights are suspended at the smallest and middle-sized cylinders, the weights will have to be in the proportion of 2 : 1; similarly, if the middle-sized and largest cylinders are used, the weights will have to bear the proportion of 3 : 2. In any case, *there will be equilibrium if the forces are such that the work done by them, if motion takes place, is equal.* If one of the forces is greater than what is required by this condition, the other force will be overcome, and motion will ensue.

Figs. 55 and 56 (p. 82) show two forms of the wheel and axle which are practically used for raising weights. In fig. 56 the wheel is replaced by a handle. Suppose the weight to be raised by the wheel and axle, represented in fig. 55, to be 50^{kgr} , the radius of the axle round which the rope is wound to be $0^{\text{m}}.1$, and the

radius of the wheel, which is turned by the hand, to be $0^m \cdot 75$. The work required for raising the weight through 1^m is 50 kilogrammetres; the same amount

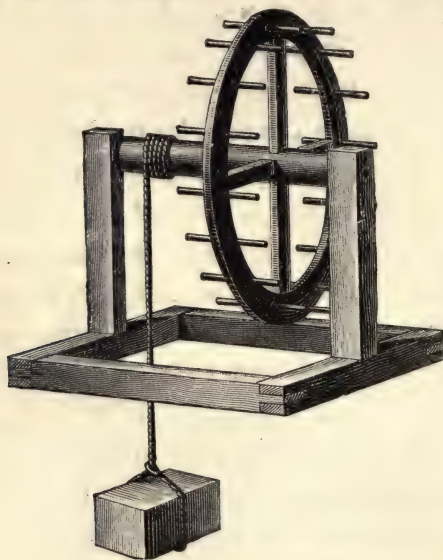


FIG. 55 (*an. proj.*, $\frac{1}{20}$ real size).

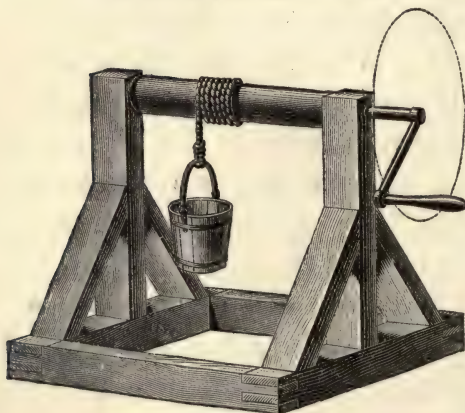


FIG. 56 (*an. proj.*, $\frac{1}{30}$ real size).

of work must be done at the circumference of the wheel. Now, a point at the circumference of the wheel describes a space of $7^m \cdot 5$, during the time in which a length c

cord = 1^m is wrapped round the axle, and the force required, multiplied into the space of $7^m \cdot 5$, must also be 50 kilogrammetres; hence the force required is $\frac{50}{7 \cdot 5} = 6^{\text{mgr}} \cdot 66$.

The above law on the equality of work holds for all simple machines; namely, the *lever*, the *pulley*, the *inclined plane*, the *wedge*, and the *screw*.

A *lever* is a rigid rod moveable about a fixed point,

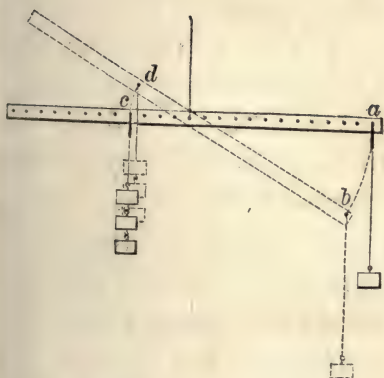


FIG. 57 ($\frac{1}{10}$ real size).

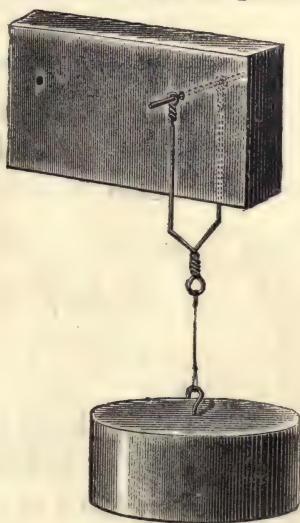


FIG. 58 (an. proj., real size).

acted on by two or more forces, which tend to move it in opposite directions. The fixed point is called the *fulcrum*.

Fig. 57 represents a form of the lever, applicable to experiments on the relations of these forces. It consists of a rectangular wooden rod, 50^{cm} long, 2^{cm} broad, and 1^{cm} thick. 25 horizontal holes are bored through it at distances of 2^{cm} from each other, the middle hole being equally distant from both extremities of the rod.

The rod, made of hard wood, and well planed, may be obtained from a joiner. The holes must be bored neatly, and clean through, their positions having been previously marked on a pencil-line ruled along the rod a little above the middle, about 6^{mm} below the upper edge, so that the rod may hang horizontally without being loaded. The readiest way of suspending the lever is to pass a thin cord through the middle hole and fasten the ends to the crossbar of the support, fig. 35 (p. 36). The weights are suspended, either immediately or by a piece of thread, from forks provided with small rings. One of these forks is shown in fig. 58; they are easily bent of thin wire, and are fixed by a straight piece of wire which passes through one of the holes.

If a weight of $294^{\text{gr}} = 0^{\text{kgr}} \cdot 294$, suspended at a distance of 8^{cm} from the fulcrum of the lever is to be kept in equilibrium by a weight suspended on the other side of the fulcrum, at a distance of 24^{cm} from it, we shall have to employ a weight of $\frac{294 \times 8}{24} = \frac{294}{3} = 98^{\text{gr}}$.

If we suppose the lever to turn through any distance, the force applied at a distance of 24^{cm} will act through the space $a b$, which is three times as great as the space $c d$ through which the force acts that is applied at a distance of 8^{cm}. But for equilibrium the work, that is the product of the force into the space, must be equal; one force must therefore be as much greater than the other as the space is less: in this case one force must be a third of the other. This relation, which is valid for all kinds of machines, may be stated thus:—

Two forces applied to a machine will be in equilibrium if the first force is to the second as the space through which the second force acts, if motion takes place, is to the space through which the first force acts; or more shortly if the forces are inversely proportional to the spaces.

This is a somewhat altered form of enunciating a law of mechanics, usually called the *principle of virtual velocities*.

The distances from the fulcrum at which forces are applied are called the *arms of the lever*. In a straight lever the spaces described are proportional to the length of the arms ; such a lever is therefore in equilibrium *if the forces are inversely proportional to the arms of the lever*. The lever shown in fig. 57 enables us to make experiments with various lengths of the arms; for instance, 70^{gr} at 14^{cm} and 98^{gr} at 10^{cm} distance from the middle, &c.

The applications of the lever are exceedingly numerous. There are three kinds of lever, distinguished from each other by the position of the fulcrum with reference to the power employed to move the lever and the resistance to be overcome by it. In fig. 59,

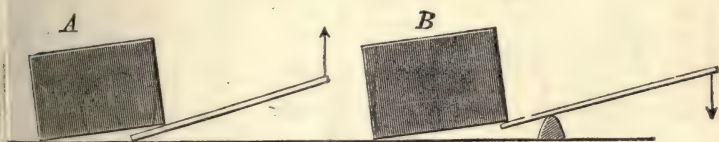


FIG. 59 ($\frac{1}{50}$ real size).

1, B, a crowbar is used in two ways as a lever, to raise a weight. At one end muscular force is applied in the direction indicated by the arrow. In raising the weight 2, the fulcrum is between the power and the resistance ; such a lever is called a *lever of the first kind* ; but in raising the weight A, the other extremity of the lever rests on the ground, and so becomes the fulcrum about which the bar is turned ; here the resistance to be overcome is between the fulcrum and the power ; this is a

lever of the second kind. When the power is applied between the fulcrum and the resistance, as in the treadle or footboard used by a knife-grinder, we use *a lever of the third kind.* A pair of scissors, nutcrackers, a pair of tongs, are respectively instances of double levers of the first, second, and third kind.

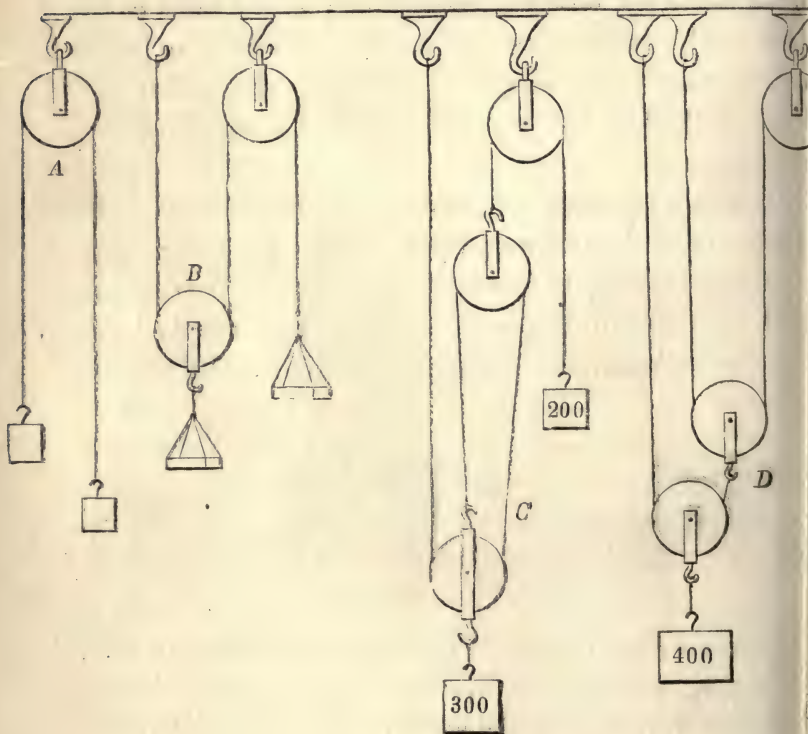


FIG. 60 ($\frac{1}{4}$ real size)

The *pulley* consists of a wheel moveable ^{round} an axis which passes through a frame called the block. A groove is cut round the edge of the wheel for the reception of a cord.

Pulleys for experiments must be very carefully made, and are best purchased of an instrument-maker. The cords must be very flexible; twisted silk is the best material. The weights may be placed in two light square boxes made of cardboard, threads being fixed to the corners and tied together above.

A pulley like that shown in fig. 60, *A*, which is attached to some support and cannot change its position is called a *fixed pulley*. The two forces applied at the ends of the cords will describe equal spaces, if motion takes place, and it follows that there will be equilibrium if the forces are equal. The fixed pulley serves chiefly for changing the direction of a force; a downward pull on one side produces an upward motion on the other.

In the *moveable pulley*, fig. 60, *B*, only one force acts along the cord; the other acts at the axis of the pulley. If the two portions of the cord after passing round the pulley are parallel, and it were required to raise the pulley through 10^{cm} , each portion of the cord will have to be shortened by this length; but as one end is fixed, the other end will have to be pulled upwards through twice that length, or 20^{cm} . The force at the end of the cord describes twice the space of the force applied at the axis of the pulley; this force must therefore be twice as great as the former if the work done is to be equal. Since weights can act only downwards, the free end of the cord, must be passed over a fixed pulley, if

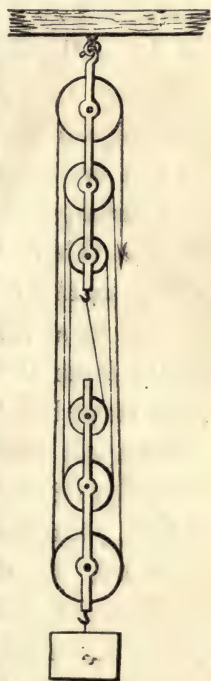


FIG. 61.

experiments are made with weights; and as the weight of the moveable pulley itself has to be supported, two small cardboard boxes or scales are attached to the free ends, into one of which sand or shot is placed until equilibrium is produced; this is done before the weights to be experimented on are applied.

Several pulleys may be combined in various ways. A simple consideration will show that in the arrangement fig. 60, *C*, the force applied to the free end of the cord passes over one and a half times the space of that applied at the axis of the lowest pulley, while in the arrangement *D* it passes over four times as great a space. The force at *C* will therefore be $\frac{2}{3}$, at *D* $\frac{1}{4}$, of the force acting at the axis of the pulley. In fig. 61 there are six pulleys; the weight to be raised is thus suspended by six cords, each of which must become shorter by the space through which the weight is to be raised. The free end of the cord will therefore have to be pulled down through a space six times as great, and the force acting at this end must be $\frac{1}{6}$ of the weight.

The *inclined plane* is chiefly used for raising weights to a certain height by the application of a smaller force than would be required for lifting them to the same height vertically.

The work done in drawing a carriage on the inclined plane, fig. 62, from *a* to *c* is the same as that required for lifting the carriage vertically upwards through the space *ab*, or *dc*, but the force required will be less than the weight of the carriage in the same proportion in which the length of the inclined plane is greater than its height. If the weight of the carriage be 200^{kgr} , the height of the plane 3^{m} , its length 20^{m} , the

work required is $200 \times 3 = 600$ kilogrammetres, the necessary force therefore $\frac{600}{20} = 30^{\text{kgr}}$. A road up a hill, a flight of steps, two long poles used for rolling a

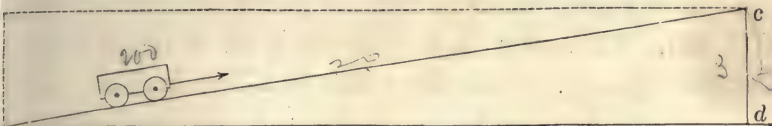


FIG. 62 ($\frac{1}{200}$ real size).

barrel up into a waggon, are familiar examples of the application of an inclined plane.

Very similar to the inclined plane is the *wedge*, fig. 63, used for splitting wood.

The thin edge is inserted in a cut previously made in the wood, and force being applied at the back or broad end of the wedge, either by pressure or a blow, the wedge is driven onward through a certain space, and the portions of wood on both sides are further separated. If a wedge 25^{cm} long and 5^{cm} broad is driven in, up to the broad end, by a force of 100^{kgr} , the space passed over will be $25^{\text{cm}} = 0^{\text{m}}\cdot 25$, and the work done $100 \times 0\cdot 25 = 25$ kilogrammetres. The portions of the log are separated by $5^{\text{cm}} = 0^{\text{m}}\cdot 05$; this is the space through which the resisting force has been overcome; this force is therefore $\frac{25}{0\cdot 05} = 500^{\text{kgr}}$.



FIG. 63 ($\frac{1}{10}$ real size).

Most of our instruments for cutting, as knives, chisels, have a wedge-shaped section, and their action is quite similar to that of the wedge.

The *screw* is, like the wedge, only a particular form of the inclined plane. If a right-angled triangle, cut out of paper, be wrapped round a cylindrical body, for instance a test-tube (fig. 64, *A*), the slope of the inclined plane will represent a spiral line, called the thread. A screw is a cylinder with a spiral ridge raised upon it. This ridge may be either angular (fig. 64, *B*, *D*), or square (fig. 64, *C*). To use the screw it is necessary to have a hollow cylinder with a groove cut

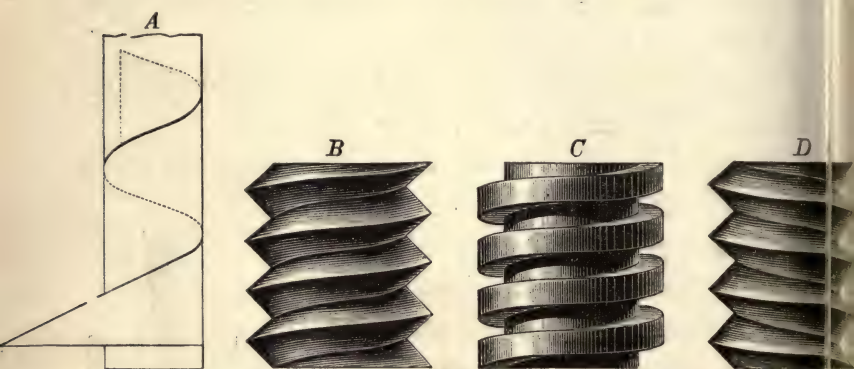


FIG. 64 (*real size*).

on the inside of it, so that the thread of the screw exactly fits into it. This hollow cylinder is called the nut. If the nut is fixed while the screw is turned, the latter passes through the nut. The converse takes place if the screw is fixed and the nut is moveable. Screws like *B* and *C*, in which each turn of the thread appears higher on the right-hand side than on the left when the screw is held upright, are called *right-handed* screws. Screws like *D*, in which the left end is higher, are called *left-handed*. The former kind is much more often used than the latter. In the screw one of the forces acts in the direction of the axis of the cylinder, the space

through which it acts being comparatively small. It amounts only to the distance between two con-

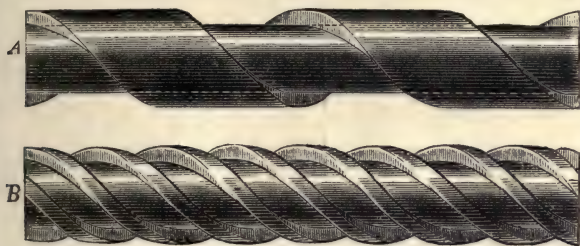
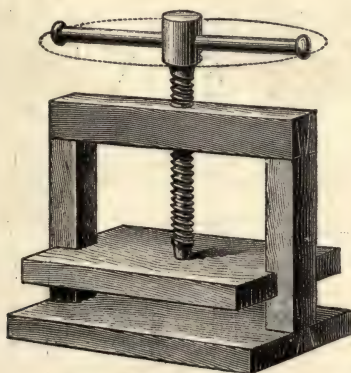


FIG. 65.

secutive threads during a whole revolution of the screw. On the other hand, the force which turns the screw acts through the circumference of a rather large circle; and, since here also the forces are inversely as the spaces, a moderate turning force produces a powerful

FIG. 66 (*an. proj.*, $\frac{1}{10}$ real size).

action in the direction of the axis. In the screw-press represented in fig. 66, the distance between two consecutive threads is $0^m \cdot 01$; the length of the handle, from one end to the opposite, $0^m \cdot 36$. Hence the space described by each extremity of the handle during one

turn is $3.1416 \times 0.36 = 1^m.130976$. If the end of the handle be turned with a force of 5^{kgr} , the work done during one revolution is $5 \times 1.130976 = 5.65488$ kilo-

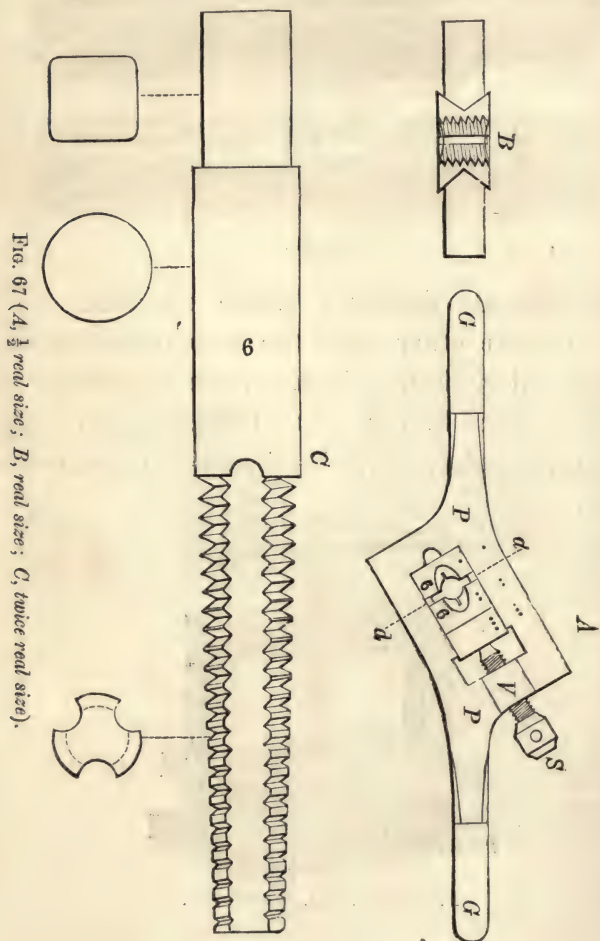


FIG. 67 (*A*, $\frac{1}{2}$ real size; *B*, real size; *C*, twice real size).

grammetres. The force with which the cylinder moves downwards is therefore $\frac{5.65488}{0.01} = 565^{\text{kgr}}.488$.

The relation of the forces is very variable in the

screw, and may be altogether changed when the distance between two threads, compared with the diameter of the cylinder, becomes so great as in the screw fig. 65, *A*. To avoid such wide threads, several threads are often wound in parallel spirals round the cylinder. In fig. 65 *B*, there are four such parallel threads.

In the construction of physical apparatus as well as for many other mechanical purposes, the screw finds many and various applications ; the student who wishes to construct his own apparatus should therefore acquire practice in cutting the necessary screws. Very small screws are generally cut by means of a tool, called a screw-plate, while the larger kinds are cut in a peculiarly constructed turning-lathe. The tool used for cutting screws of average size, which will be described here, is called a *screw-stock* or *die-stock*. It need not be very large for our purpose, but must be really good, if satisfactory and speedy work is expected from it.

The screw-stock represented in fig. 67, *A*, consists of a rectangular iron frame, having a central rectangular aperture, and being provided at two opposite corners, *PP*, with handles. The 'dies,' or half-nuts by means of which the screws are cut, are inserted in this aperture, and may be squeezed together by the screw *S*, the head of which is perforated for the reception of a pin by means of which the screw is turned and adjusted as required. The sides of the aperture are bevelled or 'chamfered' above and below, so that the dies may rest on the projecting ridge : this is shown in fig. 67, *B*, which is a section across the screw-stock along the dotted line *dd* in *A*. For about one-third of its length the chamfer is filed away and the aperture enlarged, for the removal and insertion of the dies laterally. The stock shown in the figure will cut screws of three sizes, viz. having an external diameter of 6^{mm}·5, and 3 to 4^{mm}, with 'pitches' or distances between the threads of 1^{mm}·25, 1^{mm}·0, and 0^{mm}·9 respectively. Three pair of dies are therefore required, and to avoid mistakes, they are marked by points, the number of which corresponds to a like number marked on the stock, as shown in the figure where the dies are marked 6, 6̇, and ̈. The inner surface of each die includes from a third to nearly the half of a circle, and a notch is made at the central part of each die, so that the pair of dies present four arcs and eight series of cutting points or edges.

Hollow screws are cut by means of *screw-taps*, represented in fig. 67, *C*, which also shows sections of the tool at three different points. A screw-tap is simply a screw of which great part of the

'worm,' or thread, has been removed by filing either flat surfaces or concave grooves along its length, the angles left by this operation forming a series of cutters. The head of the tap is squared to fit it into handles or a vice, by means of which it may be turned; the next portion is cylindrical, and the tap itself is filed towards the end in such a manner as to leave there only a trace of the worm. The taps are generally made in sets of three; the first (shown in the figure), called the *entering* or *taper-tap*, is regularly tapering throughout its length; the second or *middle* tap is generally cylindrical throughout with just a few threads at the end tapered off; the third tap, which is also called the *plug* or *finishing* tap, is always cylindrical, except at the two or three first threads, which are slightly reduced. In cutting a hollow screw right through a piece of flat metal, the first kind of tap is turned with its whole length through the metal; but for tapping shallow holes the second kind must be used, and it is necessary to have a succession of three or four of such taps, each a little larger than the preceding.

Of the two corresponding parts of the screw the nut is cut first. A hole is drilled in the piece of metal (see further on), and the tap worked into the hole with gentle pressure. The tap may be either fixed into the middle of a long handle, by which it can be turned with considerable purchase, or driven round by a tail-vice, whilst the work is fixed in the vice. Tap-wrenches, or levers with central holes to fit the square ends of the tap, are however better. In tapping iron or steel, which latter must be softened in the manner explained further on, the tap must be oiled with common olive-oil; for brass it must be slightly greased with tallow. Copper is badly adapted for cutting screws; when used, the tap should be moistened with soap-water. The metal piece in which the screw is to be cut is protected from injury by being placed in the vice between two flat pieces of lead (3 to 5^{mm} thick); moderately thick (0^{mm}·5) sheet-copper may also be used; the pieces should be twice as broad, and about as long, as the cheeks of the vice. They are first placed in the vice, their lower edges in a line with the lower edges of the cheeks; the projecting rims are then bent apart and hammered flat with a wooden mallet, until they have nearly the shape of the cheeks.

The cylinder for the screw is made, when practicable, of a piece of wire which is bought of the required thickness, namely that of the corresponding screw-taps. The sliding gauge, fig. 68, is well adapted for measuring the thickness of wire and many other objects. It consists of a hollow square measuring rule of brass, in which a second rule of iron moves with some little friction. Each rule carries at one end, at right angles, a projecting arm or beak; both beaks touch each other closely when one rule is completely within the

other. Objects, the thickness of which is to be measured, are placed between the beaks; the diameter of apertures, wider than the breadth of both beaks together, may be measured by inserting the beaks into the aperture, drawing them apart as far as the aperture permits, and adding the width of the two beaks, usually 15^{mm}, to the number of millimetres read off on the scale. The piece of wire to be made into a screw is fastened in a vice, while its end is placed in the die; the two halves of the die are at first farther apart than necessary, but capable of being brought together by regulating the pressure-screw

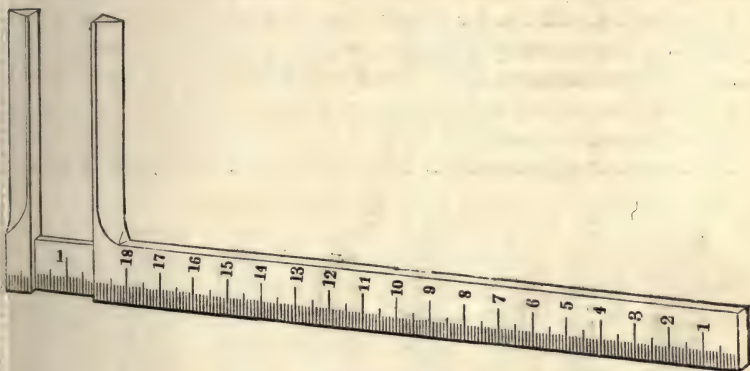


FIG. 68 ($\frac{1}{2}$ real size).

fixed in the die-stock. The die-stock is now turned, so as to worm the die on the bolt. Pressure downwards is only required in the beginning; as soon as the operator is satisfied that the shallow thread first produced is a screw line, the stock is turned as far as the screw is required to extend; it will do so without pressure. The stock is then turned backwards and taken off, the die screwed up a little closer, and again applied in the same manner; the process is repeated, closing the die a little after each operation, until the worm is cut to the required depth. The portions of metal which are removed fall through the notches of the die, but should the latter cease to proceed smoothly, it is generally owing to minute scales which clog the die and which must be removed by a pointed instrument before continuing the work. The die must be greased with the same materials as are used for the tap. In cutting metal rough edges are often produced; these must be removed by filing.

The tools required for boring holes in metal are drills, the drill-stock, and the centre-punch; these the student may easily make himself. The centre-punch is a piece of steel, either square or

round, about 1^{cm} thick and from 6 to 7^{cm} long, tapered off at one end into a short round point, which must be very sharp, but not thin. It is used for making small marks or cavities in the metal, such as those in the dies and the screw-stock.

A short piece of bar steel may be bought of the required length and thickness, but before filing it, it must be softened by making it red hot and allowing it to cool very slowly. The heating must be done over a charcoal or coke fire; common coals injure the steel. A piece of wire may be wrapt partially round it, leaving a long portion to be used as a handle for withdrawing the hot steel from the fire, and also for afterwards suspending it in order to cool it slowly; or better still, the hot bar may be laid upon ashes, which are a bad conductor of heat. Two kinds of files are required, double-cut and single-cut; the former for giving to the material the required shape, the latter for smoothing the rough surfaces produced in the former operation. Brass requires keen files, but does not

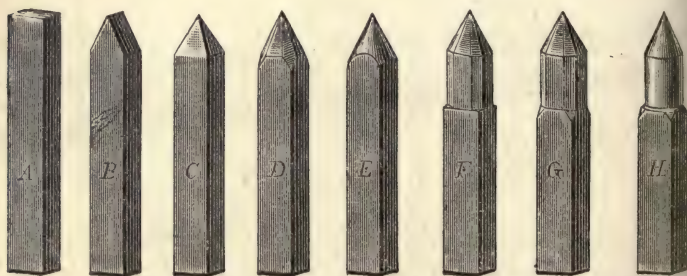


FIG. 69 ($\frac{1}{2}$ real size).

wear them so much as iron and steel, which may be worked with coarser files. It is best to have double sets of files, of each kind. Large files are not suited for small vices, like those in fig. 48 and 49; files to be used with these must not exceed a weight of 250^{gr}; such a file is about 25^{cm} long, 25^{mm} broad, and in the middle 6^{mm} thick.

The utmost care should be taken in filing to produce flat surfaces; the surfaces turned out by bad filing are always rounded. Pressing down is only required during the forward stroke; for the file does not cut during the backward stroke and pressure makes the file blunt. The file-handle is grasped with the right hand, and the extremity of the file is held between the thumb and the first two fingers of the left hand. The surface to be filed should be placed horizontally, the object being fixed in the vice so as not to project too much above it. Files should be kept clean by a wire-brush

pieces of iron sticking between the teeth should be removed by a pointed instrument.

Fig. 69, *A, B, C, D*, shows the successive shapes to be given to the point of the centre-punch. After producing the octagonal form *D* the punch is clamped between a tail-vice, which is a small tool resembling a vice, but used by the hand, and the point placed upon a square piece of wood, which is fixed between the vice in such a manner that a side perpendicular to the fibres is horizontal and uppermost. To hold the punch more securely, a small groove may be filed in the wood, in which the punch fits. The file is now guided by the right hand alone, while the punch is pressed upon the wood and turned in a direction opposite to the file, until the point is rounded off. To give a better form to the punch, the portion next to the point may be made cylindrical, as shown in *F, G, H*. The point must now be hardened. This is done by making it red hot and immersing it in water.

The dark layer produced on the surface of steel by heating may be removed by emery-powder. This is powdered corundum, a mineral of great hardness, which is to be had in various degrees of fineness. It is used in the laboratory not only for giving a smooth surface to metals but also for grinding glass, and several sorts ought to be kept. Stout paper, coarse linen, or square pieces of soft wood are covered with glue, and over the glue a thin layer of the powder is spread. After drying the rough surfaces are used like files.

Red-hot steel cooled suddenly in water becomes so hard as to scratch glass, but also so brittle that it breaks very easily. This extreme brittleness and hardness may be diminished to any required degree by the process of *tempering*; this consists in heating the steel moderately and then allowing it to cool. Pieces of steel, of the size of the centre-punch, and also larger pieces, are held by the pincers over a spirit- or gas-flame and continually turned until they are heated to the required degree; smaller objects must be heated upon a piece of sheet iron, as otherwise the heating would not be uniform. The steel, when thus heated, assumes successively different colours, first a light straw-colour, then a full yellow, then brown yellow, purple, blue, and finally a greyish black is produced. Tools for working metal are heated to a full yellow, and then immersed in water. Tools heated to a light yellow are too brittle; when heated to a brown yellow, they are too soft and do not preserve their edges when in use.

Drills are made of steel wire 3 or 4^{mm} thick, of which about 100 or 200^{gr} (1 or 2^m long) are bought, in order that the drills may be of equal thickness at the end which fits into the aperture of the drill-stock. The drill-stock, fig. 70 *A* (page 98), consists of a wooden

pulley, about 3^{cm} in diameter, and 3 or 4^{cm} long, fixed upon an iron axis, 1^{cm} thick and from 20 to 24^{cm} long. The axis may be made of a suitable piece of bar iron, and the wooden pulley fixed upon it by a turner. A square bar of iron of the proper length can be bought at any ironmonger's; by filing, it may be made eight-sided, which

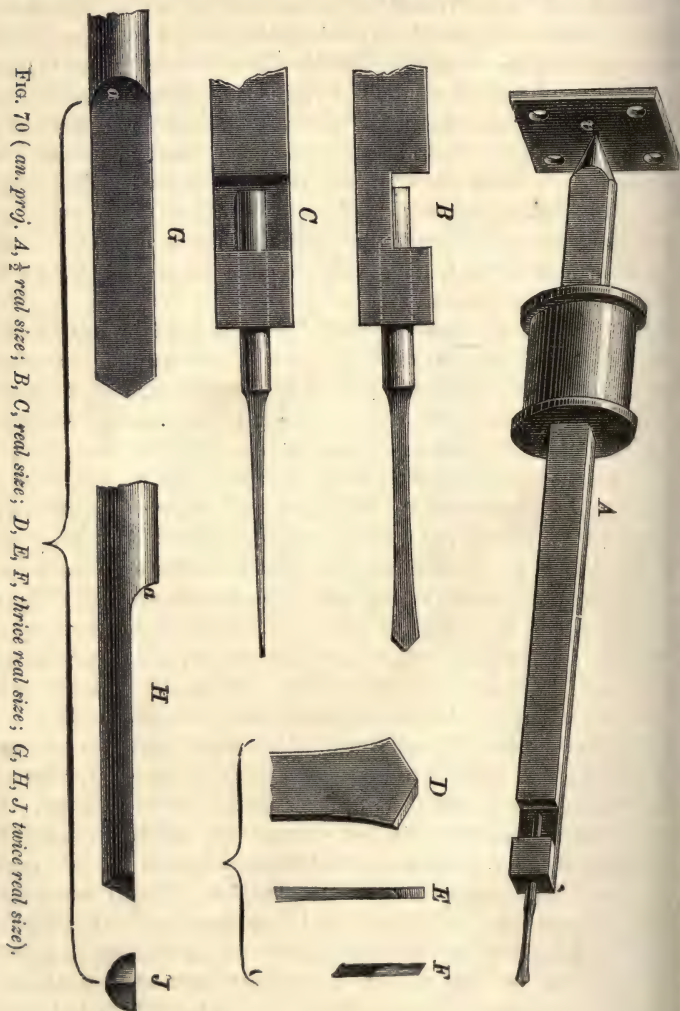


FIG. 70 (an. proj. A, $\frac{1}{2}$ real size; B, C, real size; D, E, F, thrice real size; G, H, J, twice real size).

looks better, or it may simply be left as it is. The face at each end is filed plane, and in the centre of each face a small mark is made with the centre-punch. With the first blow of the hammer the punch is struck rather gently. If the slight mark thereby produced

is seen to be precisely in the centre, the punch is placed again upon it and the cavity made deeper by a harder blow; if the centre has been missed, the small mark will not be in the way of placing the punch now upon the exact spot by the side of it, where the mark is to be made. The axis, when thus prepared, is placed into the hands of a turner, in order to have a piece of wood firmly fixed upon it, which is to be turned into the short cylinder with fillets at both ends, which forms the pulley. One end is now made into a conical point, not so sharp as that of the punch; in using the drill-stock this point rests in the cavity *v* of the breastplate. This is a plate of iron about 2 or 3^{mm} thick, and a few centimetres square, fixed with a few nails to a small wooden board, 2^{cm} thick, 8^{cm} broad, and 10^{cm} long. The drill-stock is turned by means of a drill-bow; this is made of a piece of cane, about 12^{mm} thick and from 60 to 80^{cm} long, and a strong piece of catgut, which is attached to the piece of cane by boring a small hole at each end of it, passing the extremity of the string through the hole and fastening it with a knot, much in the same way as in an archery bow. The string must be rather loose; when the bow is to be used, one end of it is placed against the table while the other is held by the hand, and the string is passed round the pulley of the drill-stock in a single loop, or with a 'round turn.' The cylindrical hole at the other end of the axis, for the reception of the drills, is pierced by the double-cutting drill, shown in fig. 70 at *G* and *H* in two positions, while *J* gives a view of the point if the drill is held horizontal in a line with the eye. The hole must be about 10 or 12^{mm} deep, and of the same diameter as the shank of the drill, 3 or 4^{mm}. A piece of steel wire of this diameter, and 5 or 6^{cm} long, is well straightened in the vice, bending it with the help of the tail-vice and using the hammer where necessary. This is filed away for a length of about 2^{cm} at one end to a *very little* less than half its thickness, as shown at *H*: if the drill is filed away only just to the middle, it will make a larger hole than is intended. At *a* the angle should be shaped by filing with a rat-tail into the curve shown in the figure; if left angular, the drill is liable in the process of hardening to crack at that place, and breaks easily. Two small facets are then formed at the end, as shown in the figure; the facets must be perfectly equal, or the hole will be larger than required. The drill, after being hardened, is clamped horizontally in the vice, and about 3^{cm} of the cutting end are allowed to project.¹ A small cavity having been made previously with the

¹ If the position of the vice is inconvenient, the drill may be fixed in a tail-vice, and this in a proper vice; it will thus be always possible to direct the drill towards the operator.

punch in the centre of the face of the axis, where the hole is to be bored, the string of the bow is looped round the pulley, the pointed end of the stock is inserted in the cavity of the breast-plate, into which a drop of oil is poured, and the plate pressed against the chest, while the point of the drill is placed in the mark or cavity made at the other end with the punch. Care being taken that the axis of the drill and the drill-stock are in the same straight line, the bow is moved with the right hand to and fro, while the stock is pressed forward by the chest upon the drill, which enters slowly into the axis of the drill-stock. The chips of metal must be frequently removed; for this purpose the drill must be withdrawn from the hole. When the hole is bored to the required depth, a square notch is filed just at the inner extremity of it, down to half the diameter of the drill-stock; the drills are also filed away to one half for a distance of about 6 or 8^{mm} from the end, so as to slide into the drill-stock in the manner shown in fig. 70, *B* and *C*. The drills are thus prevented from revolving, because the flat end of the drill rests upon the flat surface of the notch in the axis of the stock. Work to be drilled is hereafter always fixed in the vice.

The usual form of drills is shown in fig. 70, *B* to *F*. *D* is a view of the broad, *E* of the narrow face, *F* of the end. The greater portion of the length should be narrower than the cutting extremity; for the stronger kinds the wire is softened by heating and flattened at the end by hammering, the remainder being left round; the weaker kinds are thinned by filing. It is best to make them rectangular taking away on each side as much as would give them on the narrower side the appearance shown at *C*, and then curving off the narrow side to the form at *B*. The point is formed by two facets filed somewhat obliquely against the sides, so that if the broader side of the drill, *D*, be held before the eye, the point uppermost, the right facet must slope to the side seen by the eye, while the left must slope towards the opposite side; if the narrow side, *E*, be held before the eye, the facet seen must be inclined to the left side. The long narrow faces which run from the point of the drill to the shank should also be somewhat oblique, as shown in *D* and *F*. New drills may be improved by being sharpened upon a hone, placing each facet flat upon it and moving it in this position to and fro, so as not to grind the cutting edges. Blunt drills should be made soft again and prepared anew: this will require less time than that lost in using a bad tool.

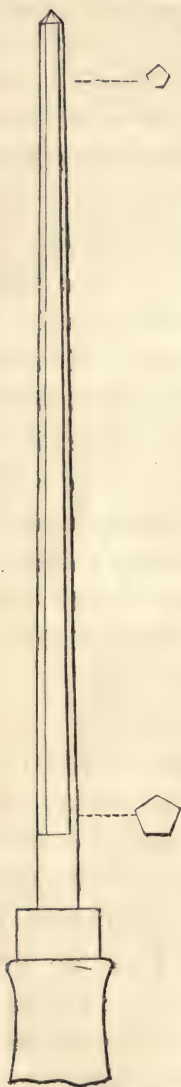
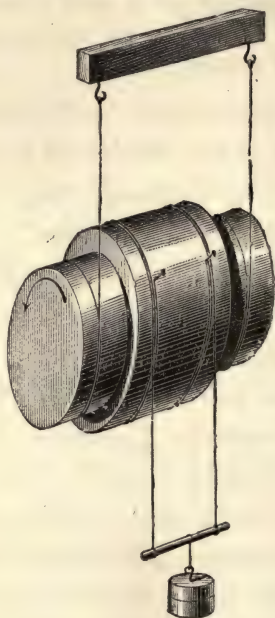
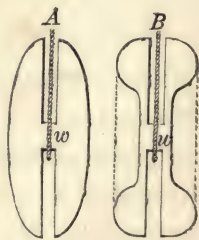
The holes for screws should first be made a little too small and then widened until the taper-tap will just go in a little way. For widening holes a tool called a *rimer*, fig. 71 (page 102), is used; this

is a five-sided, slightly tapering piece of steel fixed into a wooden handle by means of which it can be cautiously worked into the hole that is to be widened. The rimer serves not only for widening holes, but also for making them properly round and smooth. It is best to have a set, varying from 2 to 7^{mm} in thickness, for holes of different sizes.

Of the numerous illustrations of the principles involved in the action of simple machines, the following two deserve attention.

Fig. 72 is a small roller, thicker in the middle than at the ends. Two threads are fixed to the thinner ends, coiled a few times round them, and then fastened to hooks which are fixed to a support. Two other threads are fixed to the thicker part, coiled round it in an opposite direction, and the other extremities are connected by a small wooden crossbar. The roller, if left to itself, moves downwards by its weight, and the two outer threads are uncoiled from the cylinder, while the two inner threads are wrapped on to the thicker part, and in consequence of the difference of thickness more thread will be wound round the larger cylinder than is coiled off the smaller. In the figure, the circumference of the smaller ends is 6^{cm}; that of the middle part about 7^{cm}·5; hence when the roller makes one revolution it falls through 6^{cm}, while the crossbar rises through $7\cdot5 - 6 = 1\text{ cm}\cdot5$, or one-fourth of that space. It follows from the principle of equality of work that it will be possible to keep the roller at rest if a certain force be applied at the crossbar. Thus, if the roller weighs 10^{gr}, a weight of 40^{gr} suspended at the crossbar will produce equilibrium, and, if a larger weight be suspended, the roller will be made to rise while the weight sinks.

The roller may be made of strong drawing-paper. A strip, 5 to 16^{cm} broad, and about 0^m·5 long, is wound round a test-tube and the corners fastened with gum. A second strip, about half

FIG. 71 (*real size*).FIG. 72 ($\frac{1}{2}$ *real size*).FIG. 73 ($\frac{2}{3}$ *real size*).

as broad, is pasted upon the first and forms the thicker portion of the roller. According to the thickness of the paper used the

length of the second strip will vary between $0^m.8$ and 2^m . The threads are fixed either by pins or by drawing the ends of the threads through small holes made in the paper, and tying knots inside.

Fig. 73 shows sections of two forms of the *bandilore*, a toy once very common. It consists of two discs united in the centre by a short thin cylinder. At *A* the central portion is thicker, but the form shown at *B* is better. A small hole passes through the cylinder, through which a fine cord is drawn, about 1^m long, and fastened by a knot. The string is wound up so as nearly to fill the groove between the discs, and the end held in the hand while the bandilore is allowed to fall. The string becomes unwound, and the bandilore revolves more and more rapidly. The fall is slower than in a freely falling body, because a portion of the work done by gravity is expended in producing the rotatory motion. That work becomes accumulated in this form, and the rotatory motion continues when the bandilore has reached the end of the string. The string, therefore, becomes wound up again, but in a reverse direction, and the bandilore rises. It would rise again to the point of starting, if part of the accumulated work were not lost in various ways, especially by the friction of the string. The loss may, however, be compensated by jerking the hand which holds the string gently but firmly upwards at the moment when the toy arrives at the end of the string; it can thus be kept flying up and down for any length of time.

14. *Equilibrium. Centre of Gravity. The Balance.*—Cut any irregular figure, for example one like that in fig. 74, out of a piece of stout pasteboard, 20 or 30^{cm} square. At a point near the edge, as *a*, make a hole with the

bradawl and pass a thin thread through it. Tie a loop at each end, and suspend the figure by both loops to a hook in the frame (fig. 35), so that it may swing quite

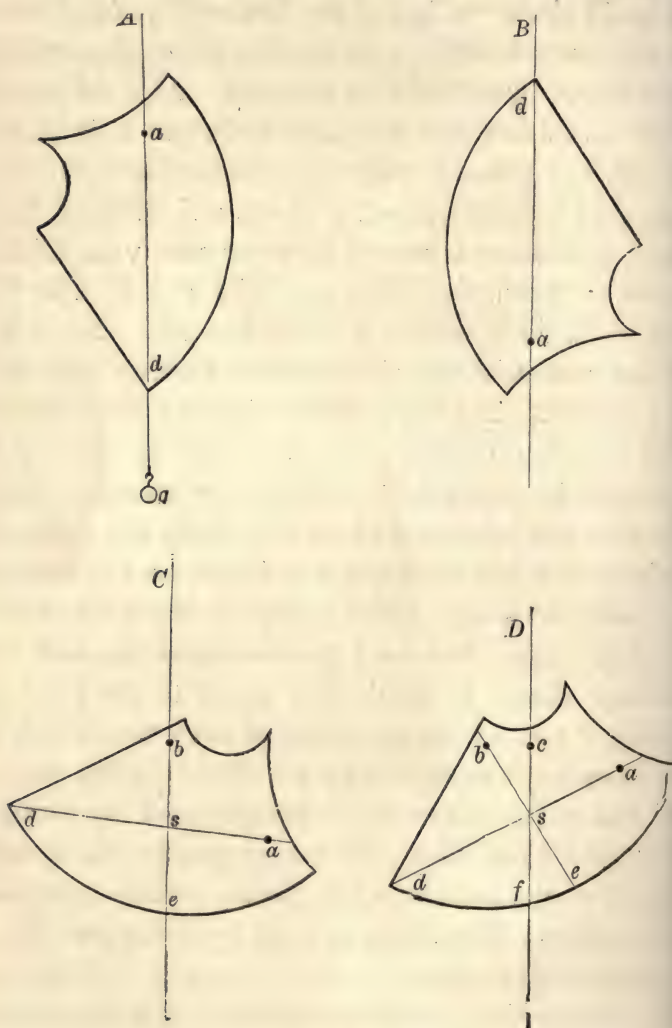


FIG. 74 ($\frac{1}{8}$ real size).

freely. After a short time it will come to rest. It will be in *equilibrium*. The figure in the diagram will place

itself in the position shown at A . If placed in any other position, the body returns by itself to that assumed at first, and there will be only one other position in which it will be also at rest—that shown at B , which is the reverse of A . But the second position of equilibrium is far from being so safe as the first: the slightest disturbance causes the body to swing round and to assume again the first position.

In order to show that the second position is the reverse of the first, a second thread with loops at the ends is passed through a , and a small weight g is suspended from both loops. The second thread indicates the vertical line through a , when the pasteboard-figure is at rest; by holding thread and figure at d between thumb and forefinger, a line can be drawn along the thread. This line will be covered by the thread when the body is suspended in the second position.

The first position—that which a freely suspended body assumes if left to itself—is the position of *stable equilibrium*. The second position—that in which a body may be placed, but which, after the smallest displacement, it changes for the first—is the position of *unstable equilibrium*.

If other points of suspension be selected, as b , c , new positions of stable equilibrium C , D , will be given to the body; but, if the vertical lines through these successive points be indicated on the pasteboard, it will be found that they all intersect in one point, s . This point is the *centre of gravity* of the body. It will be observed that, in the positions of stable equilibrium shown at A , C , and D , the centre of gravity is vertically *below* the point of suspension. In the position B , and in all other possible positions of unstable equilibrium, the centre of gravity is vertically *above* the point of suspension. Two ex-

periments are sufficient for determining the centre of gravity: it is the point in which the vertical lines through two points of suspension intersect.

If we pierce a hole through the pasteboard at s , and suspend the body by a thread passed through the hole, it will be in equilibrium in any position which we choose to give to the body; and it will, if placed in any of the four positions of fig. 74, not tend to change it for any other. This kind of equilibrium in which a body remains in equilibrium in all possible positions, is *neutral equilibrium*; and we may now extend the definition of the centre of gravity thus:—

The centre of gravity of a body is a point such that, if it be supported, the body will be in equilibrium in all positions.

A vertical line through the centre of gravity, as ad in fig. 74, A and B , be in C , cf in D , may be called a *line of gravitation*; and a body is in equilibrium if supported at any point in the line of gravitation; and it follows from what has been shown, that the equilibrium is—

STABLE, if the point of support is ABOVE the centre of gravity.

NEUTRAL " " " AT " " "

UNSTABLE, " " " BELOW " " "

In bodies with regular form, such as square or circular discs, spheres, cubes, etc., the centre of gravity is in the centre, provided such bodies are *homogeneous*, that is, are of uniform density. If a regular body consists partly of wood and partly of lead, the centre of gravity will recede from the centre towards the part which contains the lead. The centre of gravity of a triangle, or a triangular board, is at the point of intersection of

the three straight lines drawn from the middle of each side to the opposite corner, as in fig. 75. It is of course sufficient to draw only two of these lines, in order to find the centre of gravity.

If, in fig. 76, *A* and *B* are two positions of a body, suspended at *a*, and having its centre of gravity at *s*, the body will not be in equilibrium, because the vertical line through *s*, the line of gravitation, does not pass through *a*. But gravity tends to restore the body to the position of stable equilibrium, and the space which the centre of gravity must describe, until equilibrium is restored, is indicated by dotted lines. In all positions

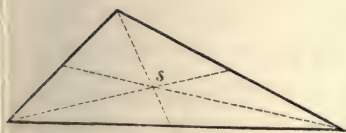


FIG. 75.

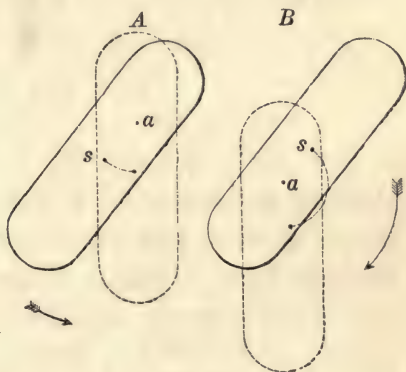


FIG. 76.

gravity tends to turn the body towards the line of gravitation drawn through the point of suspension, as indicated in the figure by arrows. It will be seen from *B*, how elongated objects, such as long poles, sticks, etc., may be 'balanced,'—on the tip of the finger, for instance. Such bodies are in unstable equilibrium, the slightest disturbance makes them fall over, but the centre of gravity being a good way above the point of support, the time required for returning to the position

of stable equilibrium is comparatively great, so that it is sufficient for bringing the point of support below the centre of gravity again, and thus maintaining the body in its unstable position for any length of time.

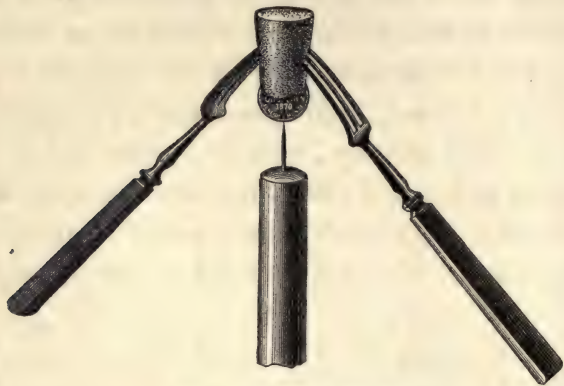


FIG. 77 (*an. proj.* $\frac{1}{3}$ real size).

The centre of gravity sometimes lies outside the body, as is the case of a ring, a horse-shoe, a triangle made of wire, and generally in bodies of a bent or angular form. Such bodies cannot be placed in a position of neutral equilibrium, because the centre of gravity cannot be supported. But it is generally very easy to place such bodies in a position of stable equilibrium. A compound body of this kind, having its centre of gravity outside of its mass, may be constructed with a pair of forks, a cork, and a small silver coin, as shown in fig. 77. If placed upon the point of a needle (fixed upon the vertical rod of the retort-stand, in which a hole is made with the bradawl) the body may be made to vibrate considerably, and even to rotate, by blowing laterally upon one of the forks without overturning. Many toys, such as tumblers

balancers, etc., are applications of this principle : their centre of gravity lies outside their mass and below their point of support ; hence they assume easily the position of stable equilibrium.

A body which is supported in two points can no longer move freely in all directions ; it can only rotate about the straight line joining those two points. If such a body rotates, every point in it describes a

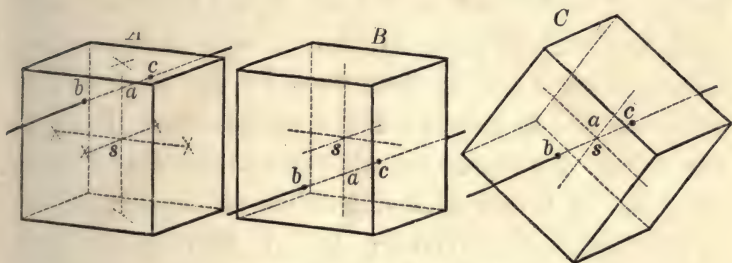


FIG. 78 (*an. proj.* $\frac{1}{2}$ real size).

circle except those points which are situated in the straight line between the points of support ; these points are at rest, they are in the same condition as the points of support. Hence if the centre of gravity of a body be in the straight line joining the two points of support, the body will be in neutral equilibrium. Such is the case with the wheel in the machine for falling bodies (p. 48) ; the centre of gravity, although not supported directly, is in the same condition as the points really supported ; the wheel is therefore in equilibrium in all positions. If we combine this with the fact, previously established, that a body is in equilibrium if supported at any point in the line of gravitation, it follows : that *a body supported in two points will be in equilibrium when the line of gravitation has one point in common with the line joining the two points of supports, or, when these*

two lines intersect. According as the point of intersection is *above, at, or below* the centre of gravity, the equilibrium of the body is *stable, neutral, or unstable.*

Experiments on this mode of support may be made with a hollow cube of pasteboard, which has its centre of gravity in the middle, that is, at the point of intersection of the three straight lines joining the centres of the three pairs of opposite faces. In fig. 78 it is *s*. At the points where the cube is to be supported holes are pierced with the bradawl and a knitting needle passed through them, which is held at both ends by the hand or fixed with one end in the fork of the retort-stand. In fig. 78, the points of support are always marked *b* and *c*, and the point of intersection of the line of support and line of gravitation is marked *a*; *A, B, C* are respectively the positions of stable, unstable, and neutral equilibrium. The line of support, represented by the knitting-needle, need not be horizontal, but may also be placed in other positions.

A cube for these experiments may be made of stout drawing-paper or thin, smooth cardboard. Fig. 79 shows the shape into which the cardboard should be cut for forming the six faces of the cube. Along the lines round the square *a*, and also along the line between *e* and *f*, the cardboard is cut half through with a knife, the whole is then bent into the shape of the cube, and thin strips

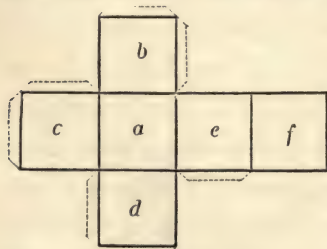


FIG. 79 ($\frac{1}{10}$ real size).

of paper pasted along the edges. In pasting together hollow bodies, the operation is facilitated by leaving such flaps as those indicated in the figure; but in this case the flaps would interfere with the position of the centre of gravity, and the cube should be constructed without making use of the flaps. If glue is used instead of paste, it should be broken with a hammer or cut with a pair of scissors, covered with

cold water for about half a day, until it swells, and then made liquid by heating in a water-bath, that is, a vessel with double walls with water between them, which thus prevent the overheating and burning of the glue. 'Glue-pots' of this kind made of cast-iron may be

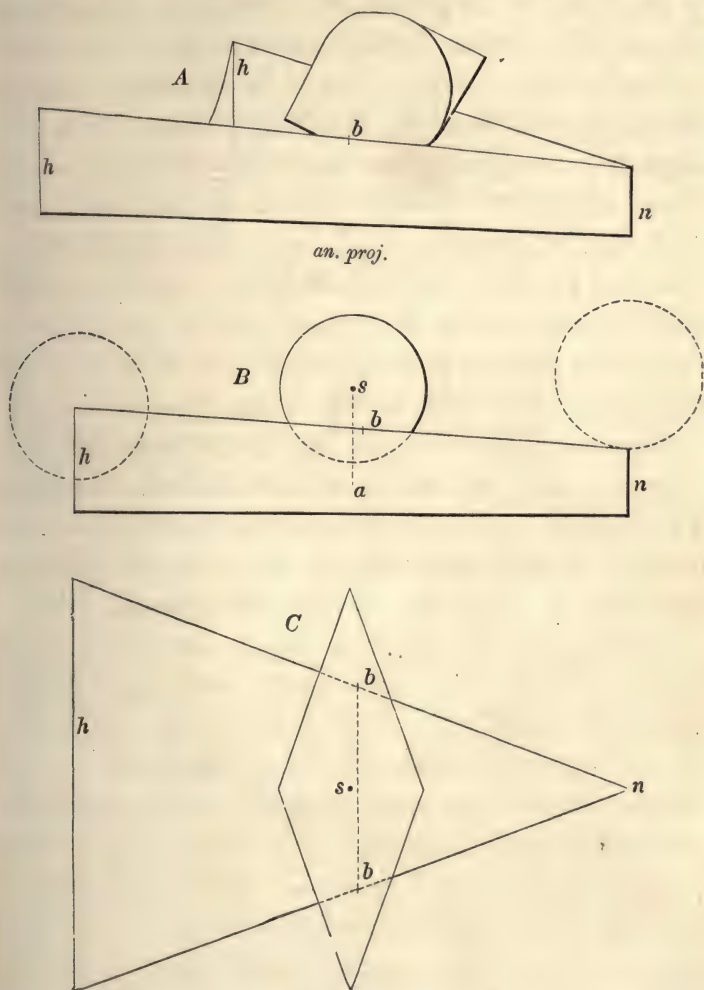


FIG. 80 ($\frac{1}{3}$ real size).

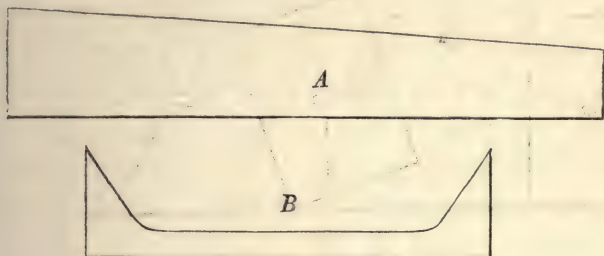
bought for a very moderate price at most ironmongers'. Glue should always be used hot and very liquid, so as to obtain thin layers: this is absolutely necessary for neat work.

A remarkable behaviour is shown by a double cone, placed upon two inclined rails which meet at a proper angle. The arrangement is represented in fig. 80, at *A* in an isometric projection, at *B* when viewed from the side, and at *C* when viewed from above.

The inclined rails are formed by the upper edges of two equal small boards, joined at their lower ends, while their upper ends are about as far apart as the distance between the two points of the double cone. The difference in the height of both ends of the rails is less than half the width of the double cone at its widest part; in the figure the heights are 7 and 4^{cm}·5, the difference therefore 2^{cm}·5, while the double cone is 28^{cm} long, and 10^{cm} wide in the middle, the half-width therefore 5^{cm}. If the double cone be placed upon the rails in such a manner that the line joining its points is parallel to the line joining the upper ends of the rails, it will run up the inclined plane, apparently in opposition to the direction in which it is acted upon by gravity. Close observation shows, however, that the cone really descends, although it moves towards the higher end of the rails. This is still more distinctly seen from fig. 80, *B*. At the lower end the cone rests upon the rails at its middle: the distance of the centre of gravity from the horizontal plane is there $4\cdot5 + 5 = 9\text{ cm}\cdot5$. At the upper end the cone rests at its extremities: the distance of the centre of gravity from the same horizontal plane is there only 7^{cm}. Again, the centre of gravity of the homogeneous and regular double cone is its centre, *s*, the vertical through *s*, *sa* in *B*, is the line of gravitation, but the line of support, *bb* in *C*, lies somewhat to the right of

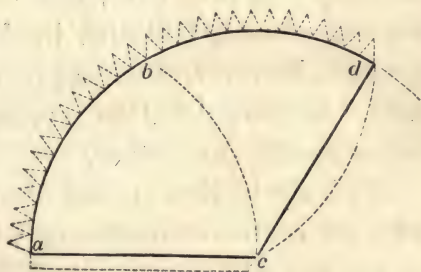
sa, as will be best seen when the cone is carefully observed while on the rails, hence the cone moves towards the left.

The rails are formed by two boards of the shape of *A* in fig. 81, 40^{cm} long; the lower ends are joined by a piece of linen glued over

FIG. 81 ($\frac{1}{5}$ real size).

the edges, the upper ends are kept apart by a board of the shape of *B* in fig. 81, 28^{cm} long, or by a piece of cord of the proper length. Stout pasteboard may be used for the rails, if thin wooden boards cannot be obtained. The double cone is best made of wood by a turner, but it may also be made hollow of pasteboard. This may be done in the following manner. With a radius of 15^{cm} describe the arc

abd, fig. 82; measure off *ab* and *bd*, each equal to the radius; join *a* and *d* to *c* by straight lines. Cut the obtained figure twice of cardboard, and apply glue along *ac* and *cd*, after having bent each figure in the shape of a cone. Unless the cardboard is very stout, little flaps may be left, as shown

FIG. 82 ($\frac{1}{5}$ real size)

in the figure, for joining *ac* and *cd*. Small triangular flaps should also be left along the arc of *one* of the figures: they serve for attaching both cones at their bases. The flaps are slightly bent inwards, so as to fit into the interior of the other cone, along the base of which, inside, a layer of glue has been spread. The joints of the two cones should be on opposite sides, or otherwise the centre of gravity will not be in the centre.

If a body is supported in three or more points, or

rests upon a surface, it is no longer possible to distinguish between the three kinds of equilibrium. A rectangular body, like *A* in fig. 83, resting upon a plane surface, behaves exactly like a body in stable equilibrium, and

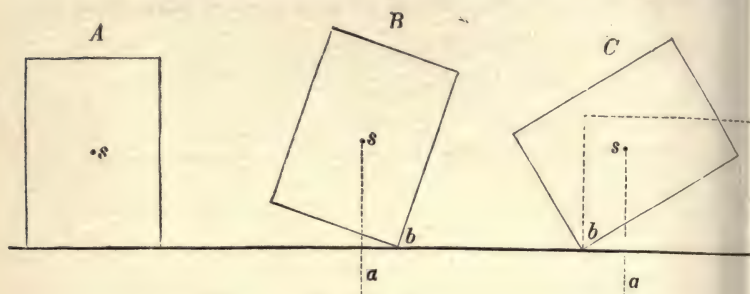


FIG. 83.

it will continue to do so, even if turned about one of its edges, as in fig. 83 *B*. But if the line of gravitation moves beyond the edge, about which the body is turned as in fig. 83 *C*, where *sa* has moved to the right of *b* the body will turn over, that is, it will assume a new position of rest, indicated by dotted lines. This new position, however, is not, as in the case of a body supported in two points, the reverse of the previous one but generally some other.

If a body be thus turned about one of its edges (fig. 84), its centre of gravity *s* will describe the arcs *ss'* or *ss''*, and will thus be raised through a definite space. The greater this space and the heavier the body, the greater must be the work, the greater also the force required for upsetting it; or, as it is briefly expressed, the greater is the *stability* of the body. If, as is the case in the body represented in fig. 84, the centre of gravity and the line of gravitation are nearer to one edge than to another, it will be easier to upset the body on the

side of the nearer edge. For in this case the centre of gravity describes the arc ss_1 , and is raised through the space as_1 ; while, if overturned about the other edge, the centre of gravity will have to describe the longer arc

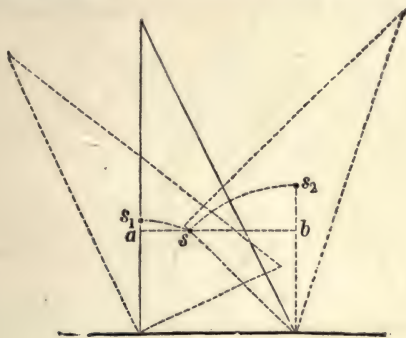


FIG. 84.

ss_2 , and be raised through the larger space bs_2 . The stability of a body is thus increased if the centre of gravity is in all directions as far as possible from the edges round which the body can turn; that is, if the base on which the body rests is as extended as possible.

The body represented in fig. 85 consists half of iron, half of wood. Its centre of gravity is, therefore, not in its centre, but falls within the mass of iron. In the position A the centre of gravity is higher than in the position B . In the first position the centre of gravity, if the body be turned about the edge, describes the arc ss_1 , which has comparatively little curvature, and at the same time the centre of gravity is raised through as_1 . In the second position, the more curved and therefore longer arc ss_2 is described by the centre of gravity, which is also raised through the larger space bs_2 . It follows that the lower the centre of gravity is situated in bodies which are equal in other respects, the

greater is the work and the greater is the force required for upsetting it.

The relation between the stability of a body and its weight, the size of its base, and the position of its centre of gravity, may be briefly expressed by saying that *the*

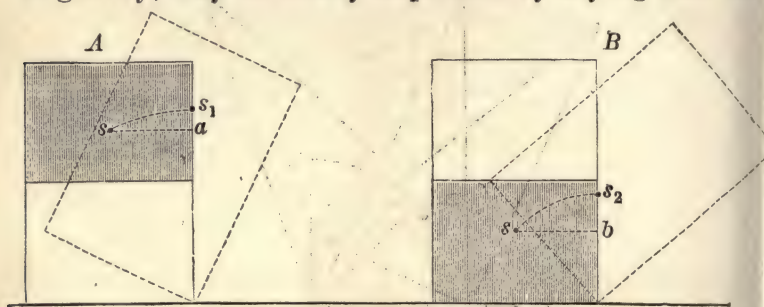


FIG. 85.

stability is proportional to the amount of work that must be done upon the body in order to upset it.

A few of the simple machines, viz., the wheel and axle, the pulley, are in neutral equilibrium, for they are supported at their centre of gravity. The lever has been used in a position of stable equilibrium, for it was supported at two points (the extremities of the central hole), situated above the centre of gravity. Being supported in this manner, the lever had only one position of stable equilibrium, and we were enabled to judge from a definite position of it, namely, the horizontal, that it was in equilibrium, and to conclude that there was no equilibrium when the lever was inclined.

The common *balance* is a straight lever supported in a position of stable equilibrium. With the help of the balance we decide whether two bodies (the body to be weighed and the counterpoise) are of equal weight or not, by ascertaining whether two forces, namely, the

weights of the bodies to be compared are in equilibrium or not when suspended at opposite ends of a straight lever. Since by art. 13 two equal forces applied in this manner cannot be in equilibrium unless the arms

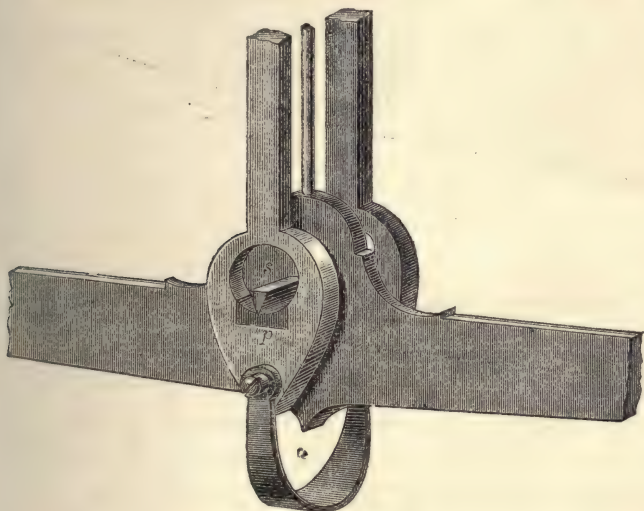


FIG. 86 (*an. proj. real size*).

of the lever are equal, *the first condition which a balance ought to fulfil is that both arms of the 'beam' are precisely equal.* But, further, a balance ought to be *sensitive*, that is, a very small difference between the weights should cause a perceptible inclination of the beam. To secure this it is necessary in the first place that the beam should turn readily. In order, therefore, to diminish friction, the beam is supported by the lowest edge of a triangular steel bar *s* (fig. 86), which passes through it at the middle. This edge is made sharp like a knife, and rests upon supports made of a very hard substance, like agate or steel, *p* (fig. 86), the surfaces of which are either concave or, in the best balances,

flat. The usual form of the beam is nearly that of a very elongated lozenge. In fig. 87, *A* and *B*, two beams are represented, the breadth being exaggerated for the sake of distinctness; in both the point of sus-

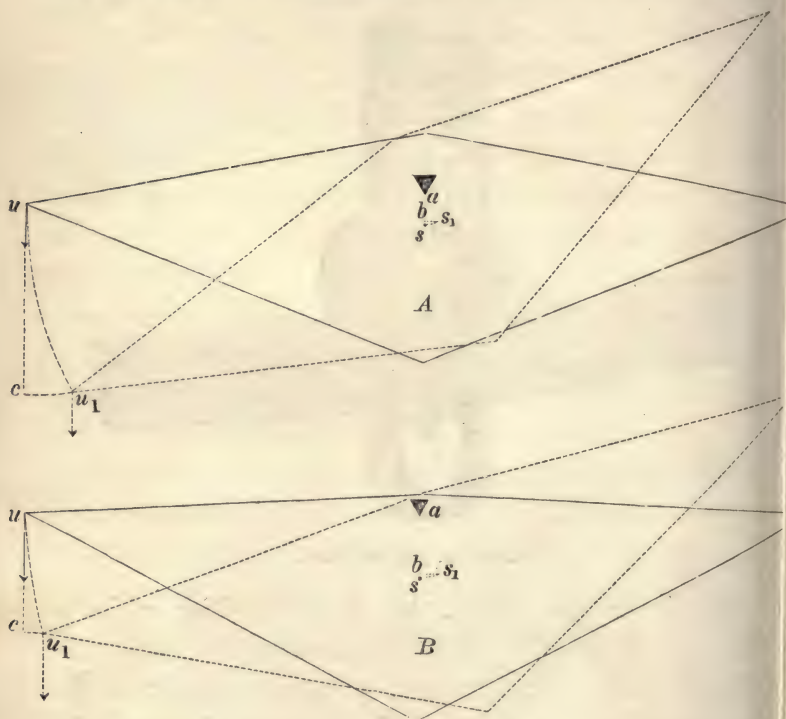


FIG. 87.

pension is marked *a*, and the centre of gravity, the point at which the weight of the beam may be regarded as acting, is marked *s*.

The sensitiveness of a balance depends on the condition that a small amount of work done should produce considerable motion. Suppose a small weight *u* to be suspended at one end of the beam. The beam will assume an inclined position, its centre of gravity will

describe the arc ss_1 , and be raised vertically through bs , while the weight describes the arc uu_1 , and descends through the space uc . The work done by the descending weight must be equal to that required for raising the centre of gravity of the beam, that is, the weight u , multiplied by the space uc , must be equal to the weight of the beam multiplied by bs . If A and B (fig. 87) be two beams of equal weight, but A has its centre of gravity nearer to the point of suspension than B , then if the centre of gravity of each beam is to be raised through an *equal* space bs , A must assume a more inclined position than B , and uu_1uc , will be greater for A than for B . But as the weights of A and B are equal and their centres of gravity rise through equal distances, the work done in deflecting them is the same, and therefore the work done by the descent of the additional weight u must also be the same in both cases; but in the first case it moves through a greater distance than it does in the second, and hence (as represented by the different lengths of the arrows in the two figures), the additional weight required to deflect the beam A must be smaller than that required to produce an equal deflection of the beam B .

Supposing, therefore, the lengths and weights of two beams to be equal, it follows that a smaller excess of weight at one end produces a greater deflection when the point of support a is near the centre of gravity s , than a larger excess does when the point of support is at a greater distance above the centre of gravity. Hence, *the second condition to be fulfilled by a good balance is that the centre of gravity be as near as possible to the point of suspension.* Both points must, however,

not coincide, for in that case the equilibrium would become unstable.

The heavier the beam, the greater is the work done in raising its centre of gravity; and the greater, therefore, the weight required for producing a given deflection. The beam must, therefore, be as light as possible. At the same time it is obviously necessary that the beam should be stiff enough to support the weights without bending, and since hollow pieces are stronger in proportion to their weight than solid pieces, in the best balances the beam consists of an open frame of brass or steel.

If two beams have equal weights and equal distances between their centres of gravity and points of suspension, but are of unequal length, as in fig. 88, *A* and *B*, the

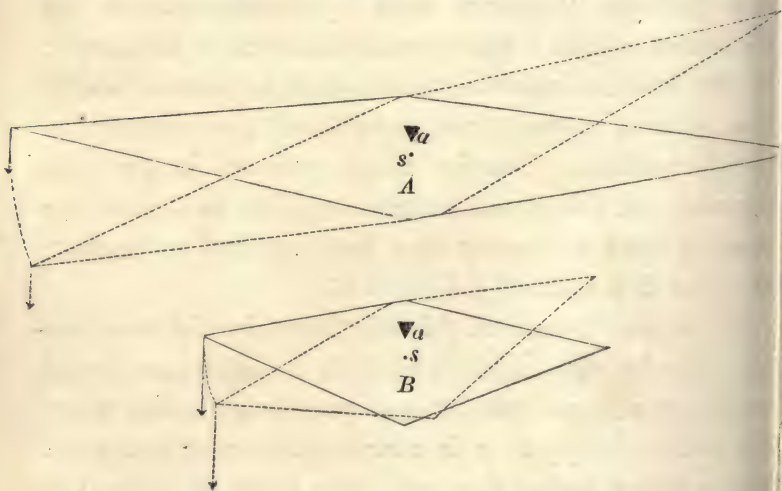


FIG. 88.

same work is required in both in order to produce a deflection through a given angle, say of 20° . But this work will be done by a smaller weight at the end of the

beam *A*, than at the end of *B*, because the smaller weight descends for the same deflection through a larger space at *A*, than at *B*. Hence the sensibility of a balance increases with the length of the beam. There is, however, a limit to the length, for the longer the beam the less is its rigidity, other conditions being equal.

It will be obvious from the principle of the lever that the scale-pans must be suspended in a manner which ensures their being always at the same distance from the fulcrum; they are therefore

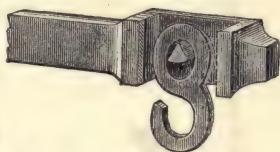


FIG. 89. (*an. proj. real size*).

suspended by hooks which rest upon knife-edges turned upwards, as shown in fig. 89. These knife-edges should be parallel to each other and also to the one which supports the beam, and all three should be in the same horizontal plane. This condition is fulfilled, in the best modern balances, by placing the points of suspension a very little above the plane of the fulcrum; when the balance is used, the load bends the beam a little and brings the points of suspension into the desired position.

A long index or pointer (which in the better balances, which are usually supported upon a pillar, points downwards to a graduated arc near the foot of the pillar) is fixed to the middle of the beam in order to show whether it is horizontal.

In order to preserve the edge of the fulcrum as much as possible the better kinds of balances are provided with an arrangement which allows of raising the whole beam with its fulcrum from the support on which the latter rests. For our purposes a common balance is quite sufficient. When anything is to be weighed, the balance may be

suspended from the frame (fig. 35) by a hook made of wire, of sufficient length to keep the scale-pans about 1 or 2^{cm} from the foot of



FIG. 90 (*an. proj.* $\frac{1}{3}$ *real size*).

the support; for some purposes it must be higher, and the hook will have to be shorter. Suitable hooks should be kept ready; if thread be used for the suspension, the balance will be unsteady. Scale-pans supported by a single rod, as in fig. 90, have the advantage of permitting a somewhat freer use of the hands; but in weighing, care must be taken to place the load not in the middle of the pan, but as nearly as possible underneath the point of suspension.

In examining a balance the beam is first suspended without the scale-pans. If the pointer indicates an inequality, the heavier arm is very cautiously corrected by filing. Since the balance may be so faulty as to render it necessary to return it to the maker, it is advisable to postpone this correction until the complete examination has proved the balance to be good in all other respects. The inequality may in the mean time be corrected by suspending a short piece of thin wire to the lighter arm.

The beam is now made to oscillate by being pressed down lightly on one side. The oscillations should be slow and continue for some time. If the beam oscillates too rapidly, its centre of gravity is too low; if it comes to rest too soon, there is too much friction at the fulcrum: the knife-edge is not sufficiently sharp.

The scale-pans are now suspended, and each is loaded with a few hundred grammes, until equilibrium is produced. When this is the case, the pans with their loads are changed to the opposite ends of the beam: if the equilibrium remains undisturbed, the balance is 'true.' But if one arm is longer, it will sink when the pans have been changed, because a larger weight at the shorter arm balanced in the first position a smaller weight at the longer arm, while in the second position the larger weight is suspended from the longer arm. Now add a small weight to the lighter scale until equilibrium is restored. If this weight exceed 0^{gr}·1 or 0^{gr}·2, return the balance; for it is not advisable to attempt any correction of this fault. But if the balance is found to have arms of equal length, correct it now by filing for any previously detected inequality in

their weight. The filing must be done while the beam is held in the hand; the vice would injure it.

Finally, the equality of the pans is tested by suspending them from the beam after it has been corrected. If the pans are unequal, fix a small piece of solder underneath the lighter pan, and file the piece until the pans are precisely of equal weight; or a piece of thin wire, adjusted to the required weight, is twisted round one of the cords or bars which support the lighter scale.

15. *The Pendulum.*—When a body is suspended at one or two points, in a position of stable equilibrium, and is drawn aside from that position, it will, if left to itself, return to it, but not immediately: it will first move past its former position to the opposite side, return again, and repeat this motion many times. Gravity compels the body to descend, until it has taken up the lowest position possible; in doing so, it gives to the body a certain velocity, it stores up in it a certain amount of work, and the work thus accumulated is just sufficient to carry the body as far beyond its position of equilibrium on the other side as it descended on this side. As soon as the accumulated work is expended, the body stops, and begins to move in the opposite direction. This kind of motion is termed *vibratory* or *oscillating motion*; a body suspended in stable equilibrium and free to move is called a *pendulum*. A pendulum solely under the influence of gravity, which accelerates its motion during the descent precisely by the same amount as it retards it during the ascent, would continue to move for ever, and its vibrations would always be equal. But friction and the resistance of the air cause the arcs which the vibrating body describes to become continually less, until finally the body is brought to rest. The vibrations of a pendulum

manifest properties which are best studied by means of a *simple pendulum*, that is, a pendulum consisting of a small heavy body suspended by a fine thread, the weight of which may be neglected, as being exceedingly small compared with that of the body. Such a pendulum was employed in art. 12, fig. 53, but it is difficult to

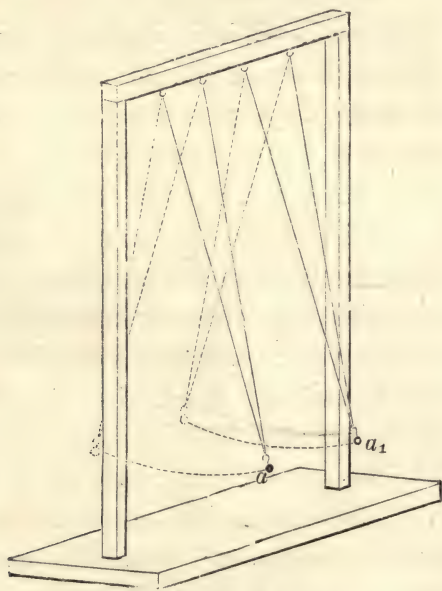


FIG. 91 (*an. proj.* $\frac{1}{10}$ real size).

make it swing long together in the same vertical plane; the best way of confining the vibrations to one plane is to hang a leaden bullet by two threads of equal length, which are fastened to points a little distance apart. Two such pendulums, of equal length, are suspended as shown in fig. 91; the threads should be of very fine silk, one of the pendulums consisting of a bullet of lead, the other of a bullet of gypsum (plaster of Paris), both being provided with small hooks. Both pendulums after

being drawn back, one by each hand, into the positions shown in the figure at a and a_1 respectively, are let go at the same instant. It may be observed that both pendulums perform their vibrations in the same time : *The time of vibration of a pendulum is not affected by the nature of its substance.* This agrees perfectly with the phenomena of freely falling bodies. The leaden bullet has a larger

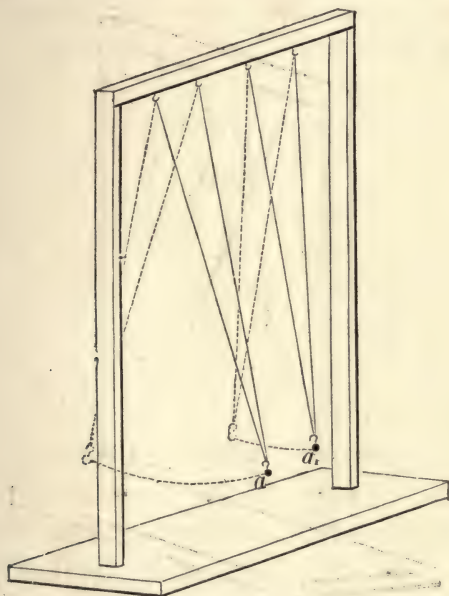


FIG. 92 (*an. proj.* $\frac{1}{10}$ real size).

mass than the other and is therefore less easily moved, but the action of gravity upon the leaden bullet is greater in the same proportion as that in which its mass is greater, hence the bullet of lead and that of gypsum move with equal velocities.

Both pendulums, which for the following experiment may both have leaden bullets, are now brought into the positions a , a_1 , fig. 92, and started simultaneously.

The arcs of vibration are now of different lengths, but the pendulum a has in the beginning of its path a steeper descent than the pendulum a_1 ; hence it acquires a greater velocity, and performs its vibration in the same time as that in which the pendulum a_1 describes its shorter path. The magnitude of the arc of vibration of a pendulum is called the *amplitude* of the vibration, and

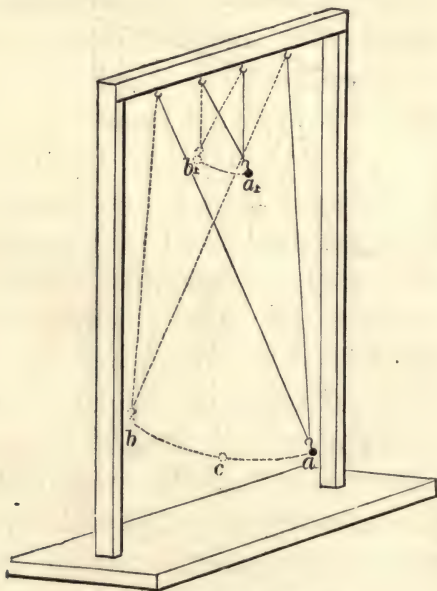


FIG. 93 (an. proj. $\frac{1}{10}$ real size).

we observe thus that *the time of vibration of a pendulum is independent of the amplitude*. This is called the law of *isochronism*. Strictly speaking, it is not quite correct. The pendulum requires a somewhat longer time for a greater arc of vibration than for a shorter; but the error committed in assuming the law to be strictly true, is very small. If we note the time required by a given pendulum to make 1,000 vibra-

tions, each having an amplitude of 5° , then if the arc of vibration were doubled, the same pendulum would make only $998\frac{1}{2}$ vibrations in the same time, and if the amplitude were four times as great (20°), it would only vibrate 993 times in that time, making in the first case $1\frac{1}{2}$, in the second 7 vibrations less. In our experiments, however, greater inaccuracies arise from the difficulty of making both pendulums precisely of equal length, than from the differences in their amplitudes.

Next let two pendulums be suspended as in fig. 93, one of which is precisely four times as long as the other, and let them be started at the same instant in the positions shown respectively at a and a_1 . The short pendulum vibrates more quickly than the long one. It arrives at b_1 at the instant when the long pendulum is at c , and when the latter arrives at b the former has returned to a_1 . While the long pendulum returns from b to a , the short one completes again a whole oscillation to and fro, so that both arrive now simultaneously at a and a_1 respectively. Two pendulums which vibrate in unequal times cannot easily be observed together at any intermediate points of their paths, but the simultaneous return to the point of starting after each whole oscillation of the long pendulum can be accurately observed, and it may thus be ascertained that the short pendulum makes twice as many vibrations as the long one. If the experiment be repeated with longer pendulums, which may be swung between door-posts, one pendulum may be made 9 times, and again 16 times as long as the other, and it will be found that in the former case 3, in the latter 4 vibra-

tions of the shorter pendulum are performed in the same time as one vibration of the longer.

The time of vibration of a pendulum depends on its length. If a pendulum is to vibrate in twice as long a time as another pendulum, it must be made $2 \times 2 = 4$ times as long; if in three times as long a time, it must be $3 \times 3 = 9$ times as long, and so on: *The lengths of different pendulums are proportional to the squares of the time of their vibrations.* The time of vibration of a pendulum may hence be varied by varying its length in accordance with this law. By 'time of vibration' we understand the time required for a whole oscillation to and fro; thus the time of vibration of the pendulum *a* (fig. 93), is the time required for moving from *a* through *c* to *b*, and back again through *c* to *a*. This may also be called a *complete period* of the pendulum's motion. What is commonly called the time of vibration, or the time of a single vibration, is the half of a complete period. A pendulum which for such a single vibration, that is, for half a complete period, requires precisely one second of time, is called a *seconds pendulum*. The length of the simple seconds pendulum, that is, the distance from the point of suspension of the thread to the centre of the small bullet, is 0^m.994, which differs only 6^{mm} from a metre.

The pendulums which are used for regulating the motion of clocks consist essentially of a heavy rod and a lens-shaped body, the 'bob.' In such a *compound pendulum* the time of vibration depends not on the length alone, but also upon its form, size, and the relative weight of its component parts. In a simple pendulum the thread is so light that its weight exerts no

sensible influence upon the time of vibration, and the bullet is so small that all its points have approximately the same distance from the points of suspension, and hence vibrate with equal velocities. But in the compound pendulum the rod is of considerable weight; the portions nearer to the point of suspension would oscillate more rapidly if they were moving independently of the lower portions; but, being compelled by the cohesion of the several parts to swing together, the result is that a compound pendulum vibrates more rapidly than a simple pendulum of equal length.

The pendulum used in the experiments on the laws of motion (fig. 44) needs to be heavy, in order that the small striking weight attached to it may be moved without sensibly altering the time of vibration. For the preceding experiments, balls such as can be made in a common bullet-mould are sufficient. Bullets of lead and gypsum have been used, because they are easily formed by means of a mould. Gypsum, a well-known mineral, loses its water when heated, and crumbles down to a white powder, which is sold under the name of 'plaster of Paris.' If the dry powder be made into a thin paste with water, and be poured into the mould, it will become solid after the lapse of an hour or two, eventually becoming as hard as the original gypsum. The hooks are inserted in the mould in the manner previously explained (p. 56, fig. 46).

The simple pendulum possesses another important property. The plane in which its vibrations are performed, remains fixed, even if the thread or wire, and with it the suspended bullet, are made to rotate about the point of suspension.

A wire, from 8 to 10^{cm} long, is bent into a small hook at one end; the other end is passed upwards through a vertical hole made in the middle of the cross-bar of the frame, just wide enough to allow the wire to turn easily, but not more. When the hook is pretty near to the bar, the wire which projects above is bent first horizontally, and ^{cm} farther on vertically, so as to form a small handle for turning. The pendulum is then suspended from the hook, the utmost care

being taken that the point of suspension be precisely in the same straight line with the vertical portion of the wire which passes through the bar and forms the axis of rotation. The rotation of the bullet will be better observed if one half of it be covered with black varnish. If the pendulum is now started carefully, so as to make it move as straight as possible, at least for some time, and the wire-handle is turned, the thread and bullet will be observed to rotate, while the plane of vibration is totally unaffected by the rotation. The result will be the same, if the handle be turned in the opposite direction. The experiment will always succeed if the precaution indicated with reference to the point of suspension be attended to, but it will fail if the latter through not being vertically below the wire describes a circle, when the handle is turned. Still more beautiful is the experiment if performed with the help of the centrifugal apparatus described in the next article, by which the pendulum may be made to rotate ten or twelve times in a second.

This striking manifestation of the inertia of matter, which compels the pendulum to vibrate in the same plane although its mass is rotating, has been applied by Foucault to prove the rotation of the earth by experiment. A very long pendulum, consisting of a wire from 15 to 30^m long, and a bob of metal weighing from 10 to 50^{kg}, is suspended from the ceiling of a very lofty room for instance, the interior of a church, in such a manner as to make it swing in the same arc, and to prevent all lateral deflections. The earth rotates from west to east. The point of suspension rotates with the earth. Since the pendulum swings always in the same plane the earth passes as it were underneath the swinging pendulum; but, as this motion cannot be observed because we participate in it, we observe that the plane of vibration of the swinging pendulum apparently rotates in the opposite direction; namely, from east through south, towards west. This rotation can only be observed after the lapse of some time; it is, there

fore, necessary to employ a very heavy pendulum which continues its vibrations for several hours.

16. *Centrifugal Force*.—When a moderately heavy stone, about 200 to 500^{gr}, is fastened to one end of a string, and whirled round by the hand so as to describe a circle, we shall find that the string is stretched, and that the strain increases as the velocity of rotation becomes greater. If the string is not sufficiently strong, the strain will break it. All

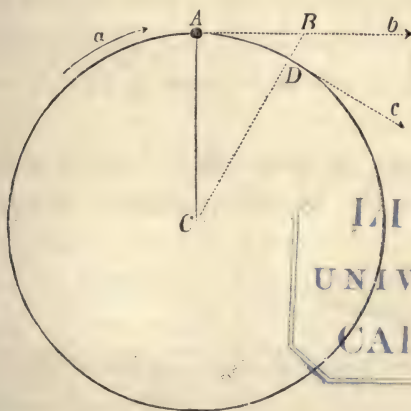


FIG. 94.

bodies which are moving in a circle are, like our stone, acted upon by a force which tends to draw the body away from the centre of the circle. This force is called *Centrifugal Force*. A moving body must, by its inertia alone, always move in the same direction; but if it is compelled to move in a circle, it changes its direction at every instant, and the centrifugal force is nothing else but the resistance of the body to this continual change in the direction of its motion. Let A, in fig. 94 represent a body, fastened to the string AC, and moving in a circle in the direction of the arrow a. At

the moment when the body is at *A*, the direction of its motion is that of the arrow *b*; and, if not constrained by the string, the body would move in virtue of its inertia towards *B*. The string, which compels it to move to *D*, must thus clearly be pulled outwards by the body which tends to move towards *B*. Arrived at *D*, the direction of motion is that of the arrow *c*, but the body is again constrained by the string to maintain the same distance from *C*, and cannot move in a straight line as it would do if moving in virtue of its inertia alone. If the string breaks, or the hand lets go, as in the case of a ball thrown by means of a sling, the motion becomes at once rectilinear.¹

Experiments on centrifugal force may be performed by means of the apparatus shown in fig. 95, usually

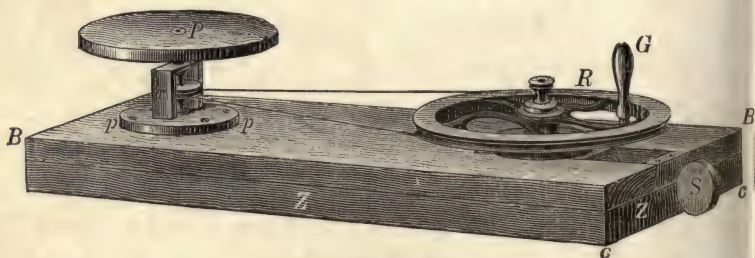


FIG. 95 (*an. proj.* $\frac{1}{8}$ real size).

called a 'whirling-table.' It serves also for experiments on sound and light, and should be purchased from an instrument-maker. On a board *B B*, which rests upon a rectangular rim or frame *Z Z*, a circular plate of iron,

¹ The line which in this case gives the direction of motion at any instant, is called a *tangent* to the circle. It is a straight line which has only one point common with the circle. Every tangent is perpendicular to the radius which is drawn from that point (the 'point of contact') to the centre of the circle. Thus *b* is perpendicular to *A C*, *c* to *D C*.

pp is screwed. The iron plate carries a rectangular frame *r*, which is made of one piece with the plate; an iron shaft passes through a hole in the board *B*, through the plate and through the frame *r*; this axle carries at the top a circular plate of wood *P*, and within the frame a small driving pulley. Fig. 96 shows a section of this portion of the apparatus, on a larger scale. *BB*, *ZZ*, *P*, *pp*, *r*, denote the same parts as in fig. 95. *AA* is the shaft, *w* the driving pulley, fixed to the axle by the pin *s*,

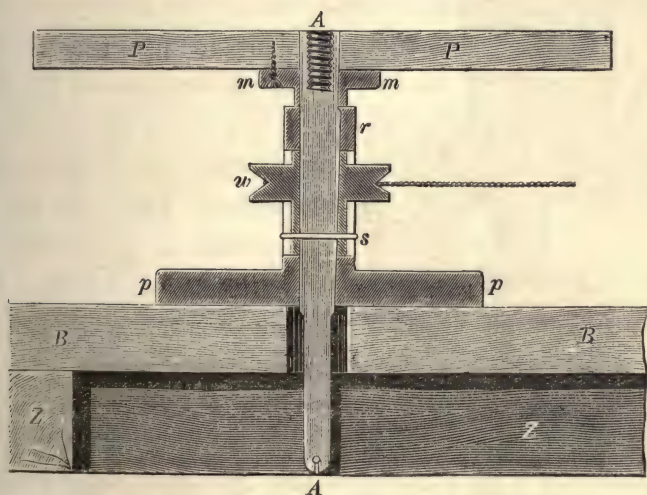


FIG. 96 ($\frac{1}{2}$ real size).

so that one cannot move without the other. The plate *PP* is secured by three screws to a small brass plate *m*, which is soldered to the shaft. In the lower end of the axle there are two holes, one passing horizontally through the axle, the other, which is rather narrow, reaches vertically from the lower extremity to the horizontal hole. A hole is also bored into the upper end, into which a screw fits for the purpose of fixing objects to the plate. An endless cord passes round the driving-pulley and the

fly-wheel *R* (fig. 95), which is turned by the handle *G*, and the motion of the fly-wheel communicates a rapid rotatory motion to the driving-pulley and the shaft. The cord can be stretched or slackened by turning the screw *S*, which moves a wooden piece upon which the fly-wheel is fixed, either from or towards the shaft, according to the direction in which the screw is turned.

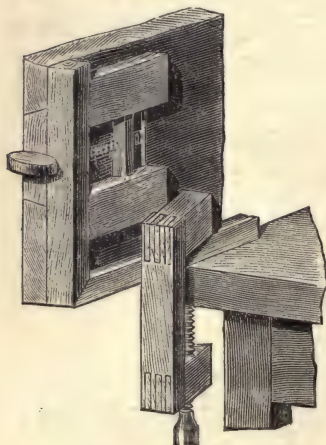


FIG. 97 (*an. proj.* $\frac{1}{8}$ real size).

For various experiments, especially on light, it is convenient to use the plate *P* in a vertical position. This may be done by fixing the apparatus in the manner shown in fig. 97, or the apparatus is provided with two hinges at *c c* (fig. 95), which permit the whole to be screwed in a vertical position upon a suitable support.

The pendulum experiment mentioned in the preceding article may be performed in the following manner. Place the whirling apparatus upon the table so that the lower end of the axle is a few centimetres beyond the edge of the table. Pass one end of a thread about 70^{cm} long, up through the vertical and laterally through the horizontal hole at the lower end of the axle, and clamp it by driving a little wooden plug into the aperture. Attach the bullet to the other end, start the pendulum, and work the fly-wheel. Even the greatest speed will not alter the direction in which the pendulum has been set to vibrate in the beginning.

To the plate of the whirling-table a disc of paste-board is screwed, in which there are six holes, each 6^{mm} wide. Two holes are 3^{cm}, two 6^{cm}, and two 9^{cm} distant from the centre. Bullets of lead, or balls of any other

substance, which have the same size as the holes, are placed in the holes, and the apparatus is worked at first slowly, afterwards more and more rapidly. Even a moderate speed is sufficient to start the bullets in the two most distant holes. If they are both of equal size, and the distance of the two holes from the centre of the plate, and their width, is precisely equal, they are thrown out at the same instant. When the speed increases, the next two bullets will roll off, and when the velocity of rotation becomes still greater the two nearest to the centre will fly off the plate. It requires, obviously, the same force to start each bullet from its place. Hence, when the two first bullets fly off, while those nearer to the centre are still in their place, we may conclude that, other circumstances being equal, the centrifugal force is greater the greater the distance of the rotating body from the centre of its path. Observing further that increased speed starts the bullets nearer to the centre, it proves that the centrifugal force becomes greater the greater the velocity of rotation, or the shorter the time required by the body for completing a revolution.

The disc is made of pasteboard, from 2 to 4^{mm} thick, with a radius of 10 or 11^{cm}; a hole in the middle, 6^{mm} wide, allows the fixing screw just to pass through the disc. The six holes for the bullets, all of the same width, are placed along a diameter, so that there are three holes on each side of the centre. A cork-borer may be used for piercing the holes, but it will become very blunt by the operation; it is better to use a kind of short hollow punch, expressly made for the purpose. Pasteboard which is not quite flat must be made moderately moist and pressed between two boards until it is dry again.

A frame may be screwed upon the plate, of which fig. 98 shows the lower part: the whole frame is repre-

sented in fig. 99. The two uprights of the frame are connected by a crossbar, which is fixed about 3^{cm} above the foot of the frame. 15^{mm} above this bar each upright is pierced by two parallel holes, about 10 or 15^{mm} distant from one another, and rather narrow. Two equal cylinders, one of wood, the other of cork, about 2 or 2^{cm}·5 long, and of the same diameter, are also pierced by parallel holes, having precisely the same

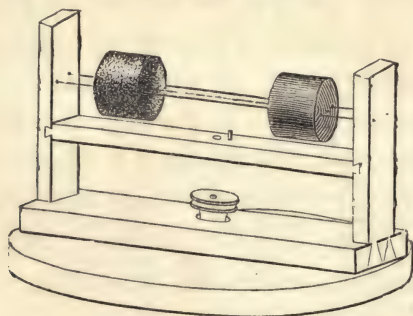


FIG. 98 (*an. proj.* $\frac{1}{3}$ *real size*).

distance between them as those in the uprights. Two threads are passed in the manner shown in the figure through the cylinders, stretched tight, and fixed by their ends to the uprights. A third thread, from 4 to 6^{cm} long, connects the centres of the two cylinders, and keeps them at a certain distance apart. If both cylinders are placed as shown in the figure, so that each may be equally distant from the nearest upright, and the apparatus be set in motion, the sound of something striking against the frame will be heard very soon. When the apparatus has been allowed to come to rest, it will be found that the wooden cylinder has moved close to the nearest upright. The heavy piece of wood has manifested a greater centrifugal force than the

lighter piece of cork. If the thread which connects the cylinders is long enough to allow the cork to be on the farther side of the centre of the frame when the wood is close against one of the uprights, it will remain stretched, because the centrifugal force tends to drive the cork to the opposite side; but, if the thread was so short that the wooden cylinder, in moving close to the frame, pulled the cork beyond the centre and to the same side of it, the centrifugal force will drive the cork to the same side as the wood, and they will be found close together.

The places for the holes are first accurately marked and the holes are best pierced by a red-hot wire, from 0.5 to 0^{mm}.7 thick; the wire will have to be heated repeatedly before the frame is perforated. For the cork cylinder a common cork of the proper size will easily be found; the wooden cylinder is cut first into shape with a knife; a soft kind of wood (the wood of the limetree, for instance) is best for the purpose. It is then rounded off with a rasp. For perforating the cylinders the wire should be somewhat thicker, from 1 to 1^{mm}.5; the thread (silk or linen) for connecting the cylinders is passed with a needle through the cork, and fixed by a knot on the other side; the wooden cylinder must be perforated in the middle, the thread is passed through, and fixed on the other side by a small plug of wood. The threads between the uprights should be of silk. A small piece of wood or wire is tied to the end of a thread of silk, about 30^{cm} long, and prevents that end from slipping through the hole; the other end is passed through one of the holes from the outside to the inside of the frame, through both cylinders, through the corresponding hole in the opposite side of the frame, then back through the adjacent hole, through the second holes of the cylinders, and finally through the hole next to the one through which it was passed first. The thread is now tightly stretched, and clamped in the hole by a small wooden plug, which should be allowed to project about 0^{cm}.5. A couple of centimetres of thread should also be left, so that the thread may be withdrawn, after removing the little plug, and used again for a repetition of the experiment.

In a soft or pliable body centrifugal force may cause a change of form. All its parts tend to recede from

the axis round which it rotates; and if this axis is vertical, centrifugal force will tend to increase the breadth of the body; in the case of a sphere the tendency will

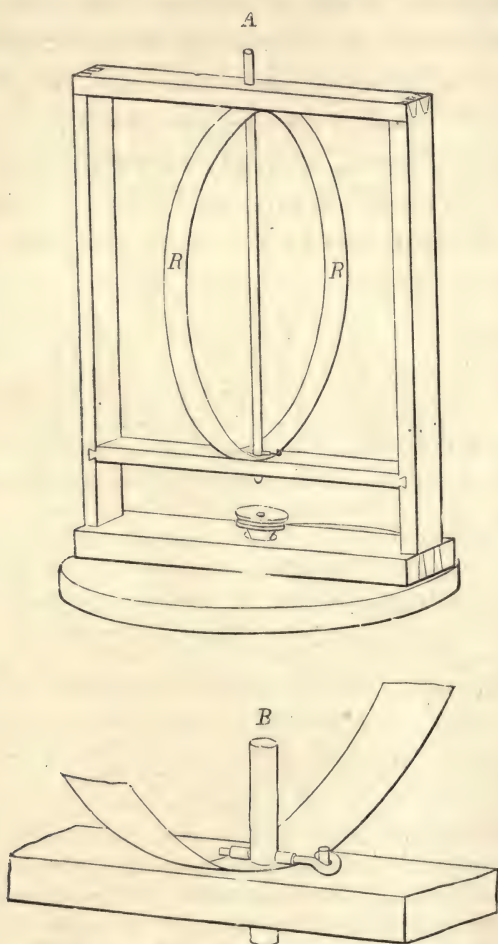


FIG. 99 (*an. proj.*: $A \frac{1}{3}$ real size; B real size).

be to make it more or less flat. The figure of the earth is that of such a flattened sphere; accurate measurements have shown the length of a straight line draw

from one pole to the other, that is, of the axis of rotation, to be 7899·1 English miles, while the distance from any point of the equator to the point exactly opposite is 7925·6 English miles, the former being thus 26·5 miles shorter. This 'compression of the earth,' is due to centrifugal force, in consequence of the earth's rotation.

This effect of centrifugal force may be demonstrated by means of a ring, *RR*, fig. 99 *A*, placed within the frame of the whirling-table; a vertical spindle passes through two opposite apertures in the ring, and is firmly connected with it at the lower aperture, so that ring and spindle rotate together; through the upper hole the spindle passes loosely. If the apparatus be set to rotate moderately, the ring presents the appearance of a transparent globe; this phenomenon is often observable in rotating bodies of certain forms, and will be alluded to, further on, in the chapter on Light. If the speed is increased, the ring contracts in the direction of the axis, and assumes an elongated shape, that of a compressed globe, of which the outline is no longer a circle but an ellipse. When the rotation ceases, the ring returns to its circular form.

The ring is made of a very thin sheet of brass, if possible only 0^{mm}·1, or at most 0^{mm}·2 thick, of which a strip is cut, 44^{cm} long, and from 12 to 15^{mm} broad. Precisely at the middle of the strip, and 1^{cm} from each end, a hole is punched, the edges of the holes are hammered flat, and the ends soldered over one another so that the two end holes fit exactly over each other. A circular ring is thus formed with two holes through it opposite each other; these holes are widened with the rimer, until they just allow the spindle, a steel wire of about 3 or 4^{mm} diameter, to pass easily through. The soldered portion forms the highest point of the ring; at both sides of the lower aperture short tubes of brass are soldered

on, which serve for fixing the ring to the axis, as shown in fig. 99, B. These little tubes, 4^{mm} long, 1^{mm} wide, are made by heating a small sheet of brass, 8^{mm} long, and 4^{mm} broad, and bending it after cooling round a wire 1^{mm} thick; the flat pliers are used for pressing the brass close to the wire. The spindle passes through two holes, which are bored through the two crossbars of the frame, just wide enough to fit the spindle moderately tight. The spindle is about 16 or 17^{cm} long; 1^{cm} from its lower end a horizontal hole, 1^{mm} wide, is drilled through it, and a pin, 2^{cm} long, made of wire, with a small ear at one end, is pushed through the two tubes and the hole in the spindle. The ear should just fit round a wire peg driven into the crossbar; this will ensure that frame, ring, and spindle rotate together. For the peg, drive a wire-pin into the crossbar.

The flattening of a globe may be more beautifully shown by a drop of oil, suspended in a liquid, as in art. 3. If a circular disc of metal with a wire through the centre of it be placed within such a drop, and made to rotate, adhesion causes the oil to participate in the rotation; it flattens out even on applying a moderate speed, and if the velocity increases the oil leaves the disc altogether and forms a circular ring surrounding the disc; if at this moment the rotation is stopped, the oil contracts again to a globe round the disc, and the experiment may be repeated.

Cut a circular disc of thin brass, 12^{mm} in diameter, punch a hole in the centre, and solder it to a straight piece of wire from 2 to 4^{mm} thick, and about 20^{cm} long, about 1^{cm} distant from one end. Pass the wire through a glass tube 15^{cm} long, just wide enough to allow the free motion of the wire, but not wider. Fix upon the end of the wire which projects from the glass-tube a small cork about 6^{mm} thick. Pass one end of a piece of india-rubber tubing, 4^{cm} long, over the cork, and the other end over the lower extremity of the shaft of the whirling-table, so as to connect them, but not too stiffly. Raise the apparatus above your table, by means of little boxes, stools, etc., so that the disc upon the wire be a few centimetres above the table. Moisten the disc, and the wire about 1^{cm} above and below the disc, well with oil; clamp the glass tube, in a perfectly vertical position, and so as to be in one straight line with the shaft, into the retort-stand, allowin

the disc to project 2^{cm} below the tube. Place the vessel for the alcoholic mixture, so that the disc may be in the middle of it; fill the vessel with the mixture, and form a globe of oil, about 3^{cm} in diameter, with the pipette, round the disc. If the globe rises too much above the disc, add a little alcohol; if it shows a tendency to sink, add a little water. The flattening of the globe requires so little speed, that it is only necessary to place the point of the finger near the edge of the wooden plate of the apparatus, and move it slowly round; if greater speed is given by the fly-wheel, the oil forms a ring freely suspended round the disc. The apparatus should be stopped immediately when the ring is formed, or otherwise it soon breaks up into single drops which do not again combine into one. The flattening alone may be shown, without the whirling-table, by bending the upper end of the wire which projects from the glass tube into a small handle for turning. To see the form of the globe better at a distance, the oil may be coloured by placing a few pieces of alkanet root in it and leaving them there for some time before using the oil.

A circular disc, *a b*, fig. 100, of stout pasteboard (3 to 4^{mm} thick), of 25^{cm} diameter, is suspended to the lower end of the shaft of the whirling-table by means of a semicircular hook fixed into the middle and a straight wire about 60^{cm} long and 1^{mm}·5 thick, the apparatus projecting from the edge of the table as in the pendulum experiment. It is obvious that the wire itself prevents the disc being quite vertical: the point *c* will be at some little distance from the wire, in the figure to the left of it, while the lower portion inclines to the right. As soon as rotation commences, the centrifugal force tends to throw all parts away from the axis of rotation, that is, from the vertical line through the centre of the disc, about which the latter rotates; hence the disc assumes first the oblique position *c d*, and very soon it places itself horizontally, *e f*.

If the disc be suspended from a point near the edge, by simply hooking the wire into a hole punched close

to it, it will rotate, when the motion begins, in its vertical position; but as soon as the rotation becomes more rapid, or if the disc be ever so lightly touched and thereby displaced from the vertical position, the centrifugal force drives the opposite sides of the disc as far as possible from the axis of rotation, and causes the

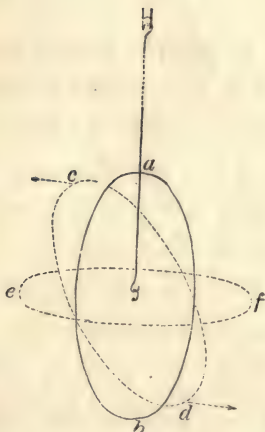


FIG. 100 (*an. proj.* $\frac{1}{8}$ real size).

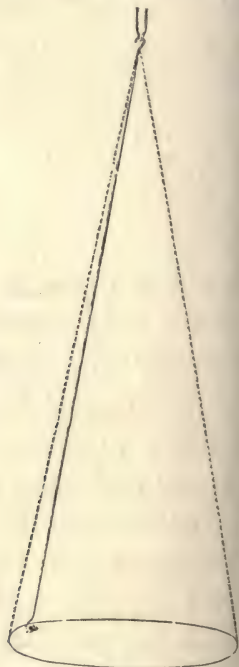


FIG. 101 (*an. proj.* $\frac{1}{8}$ real size).

disc to place itself horizontally, as in fig. 101. In this interesting experiment the centrifugal force becomes, with sufficient velocity of rotation, so powerful as to overcome the force of gravitation.

The little hook is bent of a short piece of wire. The ends are pushed through two holes punched on opposite sides of the centre and the projecting portions are then bent at right angles with the flat pliers, or the ends may be twisted.

The preceding experiments have proved that the centrifugal force increases with the weight of the rotating body and also with its distance from the axis of rotation; the force is directly proportional to these two magnitudes. A body three times as heavy as another body has three times as great a centrifugal force, if all other conditions are the same; a body five times as far away from the centre as another, has five times as great a centrifugal force, if the time occupied by one rotation is the same for both.

We have further seen that the centrifugal force becomes greater, if the velocity of rotation increases; but it is not simply proportional to the speed. If the velocity is doubled, that is, if the time of rotation becomes half of what it was before, the centrifugal force becomes four times as great; if the velocity is trebled, the centrifugal force is nine times as great: in other words, the centrifugal force is directly proportional to the square of the velocity.¹

A practical application of centrifugal force is seen in the *governor* of a steam-engine. This consists of two heavy balls suspended by rods which are hinged to a vertical shaft. Motion is imparted to this by means

¹ The centrifugal force of a body moving in a circle is found by multiplying its weight by its distance from the axis of rotation, expressed in metres, and by the number 4·025,—and dividing the product by the square of the number of seconds required for one revolution. Thus a stone weighing 400^{gr}, attached to a string 1^m·5 long, and whirled round once in 2^s, has a centrifugal force of $\frac{500 \times 1\cdot5 \times 4\cdot025}{2 \times 2} = \frac{3018\cdot75}{4} = 754\text{gr}\cdot69$, and this is

the force with which the string is stretched. Again, a leaden bullet, weighing 20^{gr}, and 6^{cm} = 0^m·06 distant from the axis would, if fixed to the plate of a whirling-table which makes twelve revolutions in one second (time of rotation = $\frac{1}{12}$ th of a second), tend to fly off with a force of $\frac{0 \times 0\cdot06 \times 4\cdot025}{\frac{1}{12} \times \frac{1}{12}} = 4\cdot83 \times 144 = 695\text{gr}\cdot52$.

of a strap, which passes round the shaft of the fly-wheel or some other convenient part of the engine, and then round a driving-pulley fixed upon the vertical shaft. When the speed of the engine is increased, centrifugal force drives the balls apart, and in receding from the shaft they move a collar which can slide loosely up and down it, and is connected, by a series of levers, with the throttle-valve which regulates the supply of steam; this valve is thus partly closed, and the speed diminishes. These balls keep the speed nearly uniform; for if it diminishes too much, they fall and thus open the throttle-valve to a greater extent, allow more steam to pass, and the speed increases again.

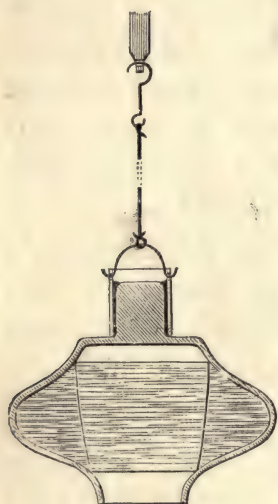


FIG. 102 ($\frac{1}{3}$ real size).

Centrifugal force acts upon liquid and gaseous bodies in the same manner as upon solid bodies. One effect upon liquids has been studied already in the experiment on the flattening of a liquid globe. Fig. 102 is a section of a shallow round glass vessel (the reservoir of a paraffine lamp), with its mouth, which is moderately wide, turned downwards. Opposite to it, it has a short stem which is firmly inserted in a brass collar provided with a handle. To the latter a stout piece of string, or 3^{mm} thick and 50 or 60^{cm} long, is tied, the other end of which is suspended by a hook from the lower end of the axis of the whirling-table. The vessel being held mouth upwards, is half filled with

water, which may be coloured with magenta, closed with a flat cork, and suspended as in the figure, in which the cork is not shown. Setting it in rotation, first slowly, but gradually more and more rapidly, the water will fly from the middle of the vessel towards the sides, finally leaving the central portion without water, as shown in figure.

In this state of matters the cork could be dispensed with, and the water would not run out. But as it is not well possible to withdraw the cork from the mouth while the vessel is in rapid rotation, the use of the cork may be altogether avoided. It will be seen farther on, when speaking of the pressure of the atmosphere, that if a vessel be filled with a liquid and its mouth be covered with a piece of stiff paper, the liquid will not run out if the vessel is inverted. Out of a piece of stiff drawing-paper, or an old playing-card, cut a rectangle, 10^{cm} long, 5^{cm} broad; fill the vessel nearly half with water, press the paper with the fingers of the left hand upon the mouth, and invert the vessel with the right hand, after having placed upon the table a china plate so as to receive the few drops which will run out. As soon as the paper cover is in a perfectly horizontal position, the hand may be withdrawn. The plate should be kept underneath the vessel during the experiment, in case of accidental discharge of the water. The rotation must be very gradually increased, otherwise the string gets twisted and knotty. When the water is observed to have left the paper altogether, the forefinger is brought near it from the side, and as soon as it is touched the paper will fly off; if you are not quite sure of the steadiness of your left hand, leave the handle of the flywheel for a moment, and use the right forefinger. When the rotation is very rapid, it will, by the inertia of the apparatus, go on with sufficient speed to allow you a few moments for the removal of the paper cover. When the experiment is to be finished, and you cease to work the handle, the vessel will rotate longer than the apparatus, the cord becomes twisted and shorter, and the vessel rises. Therefore follow the vessel with your plate, in order to prevent both the breaking of the vessel or of the plate in case the cord should break, and also the splashing about of the water when it begins to leave the mouth of the vessel; but take care not to touch the vessel with the plate.

A suitable vessel, 10 or 11^{cm} wide, rather shallow, can easily be selected from the stock of a dealer in paraffine lamps. The collar is

bent of a piece cut out of a sheet of zinc, soldered, and a round handle of iron wire inserted in two opposite holes punched in the collar; the ends of the handle are bent into hooks. The stem is carefully heated until hot enough to melt sealing-wax, covered while hot with a layer of wax, the collar is then heated and pushed upon the stem. After cooling, the sealing-wax which has oozed out all round is removed with a knife.

The *centrifugal drying machine* is another application of this force; it is in use in laundries, dyeing works, etc., and consists of a large hollow cylinder, the bottom and sides of which are perforated by a number of holes. The linen to be dried is put into this, and the cylinder is then made to rotate rapidly; in this way the linen is closely pressed against the sides, the water is given off and thrown away through the holes of the cylinder.

If the hand is brought near from the side to the rotating plate of the whirling-table, we feel that the air is rapidly thrown in all directions; the particles of air nearest to the plate are carried by the latter round in a circle, until they fly off at a tangent. In order to set the air into rotatory motion, a disc of pasteboard, 16^{cm} in diameter, upon which eight perpendicular radiating strips (indicated by dotted lines in fig. 103) are fixed, is screwed to the plate of the whirling-table. This arrangement is surrounded by a cylindrical cover made of pasteboard, just wide and high enough not to touch the radiating strips at the sides and above, when they are rotating. There are two apertures at the bottom of this cap, which permit the cord of the apparatus to pass. In the middle of the top is a circular hole 4^{cm} in diameter, and laterally, in the direction of a tangent to the cylinder, there is fixed to it a square tube *rr*. When the plate is set in

rotation, the air within the radiating strips is compelled to rotate with it, and is expelled by centrifugal force through the tube as a powerful current, while a new

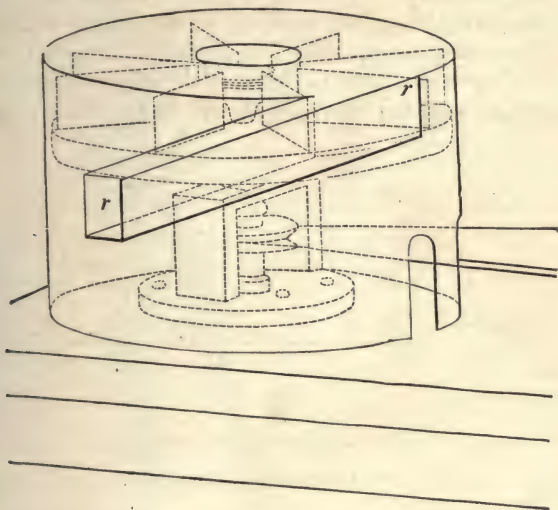


FIG. 103 (*an. proj.* $\frac{1}{3}$ real size).

supply of air is conveyed into the interior from the outside through the circular hole at the top.

Similar contrivances are employed on a large scale in various technical arts, for the purpose of producing powerful currents of air, as in mining, smelting, etc.

The radiating strips are cut from stout drawing paper, 1^{cm} wider than their required height; they are sharply folded 1^{cm} from the edge, along their length, and the portions bent in are glued to the disc, radiating regularly from the centre; after drying, every strip which is not quite vertical is bent straight with the hand. The cap should be made of rather thin cardboard; fig. 104 represents a model, on a small scale, for cutting the cardboard. In cutting it out and putting it together the following points must be attended to:—1st, The circumference of the piece which forms the top of the cap is 3.14 times as great as its diameter, but the strip which forms the cylinder must be taken about 1^{cm} longer than this, since the external diameter of the cap is greater than the internal; 2nd, The curved

line gh is an arc of a circle described from the point i with radius ig , which is equal to the radius ed of the top piece; 3rd, The knife must cut through the card-board along all lines drawn full in the figure; but not much more than half through along the dotted lines; the lines marked thus $----$ are not to be cut at all; they are merely to facilitate the correct drawing of the figure on the card-board, before cutting it out; 4th, The piece $bcrs$ is glued with its whole surface upon the piece $adpq$, after the edges bc and ag have been sharpened with the knife, as shown in fig. 104 B ; the strip

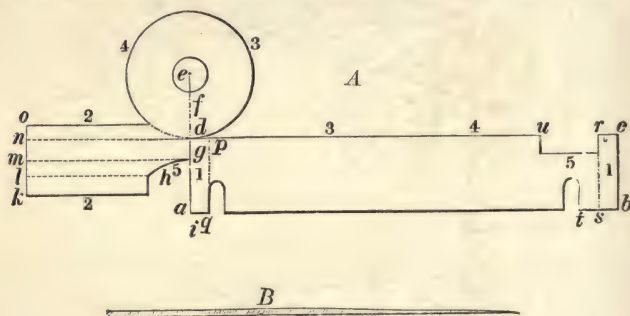


FIG. 104 ($A \frac{1}{10}$ real size; B real size).

should be bent with the hand, as nearly as possible, in the form which it is to have afterwards. The piece $bcrs$ is required for giving firmness, which would be wanting if rs were glued upon ad immediately, there would also in that case probably be an angle at the joint; 5th, The portions which are to be glued upon one another are marked by the same figures; 6th, For a cap of 16^{cm} in diameter, the following are the dimensions of the various parts in the figure:—

$$de = gi = 8^{\text{cm}}.5; ad = bc = 10^{\text{cm}}.0; ef = 2^{\text{cm}}.0$$

$$dr = as = 54^{\text{cm}}.5; mn = lk = 2^{\text{cm}}.5; ru = 7^{\text{cm}}.4$$

$$cr = bs = 2^{\text{cm}}.5; ml = no = 2^{\text{cm}}.0; aq = st = 2^{\text{cm}}.5.$$

The apertures for the cord of the whirling-table are 4^{cm} high, and 2^{cm} wide. The whole will be more durable if pieces of thin linen are glued over the joined parts, and by pasting some glazed paper all over it, the cap may be made to look neater.

The *centrifugal railway* shows a curious effect of the same force. Fig. 105 represents the essential part of it, namely, a grooved rail having a **V**-shaped section; the upper part forms a straight incline, while the

lower portion is a circle, or, more correctly, the spiral thread of a screw. A ball of lead or glass, placed at the top of the groove attains a certain velocity in descending the incline which forms the first portion of its path. On reaching the curved portion, it

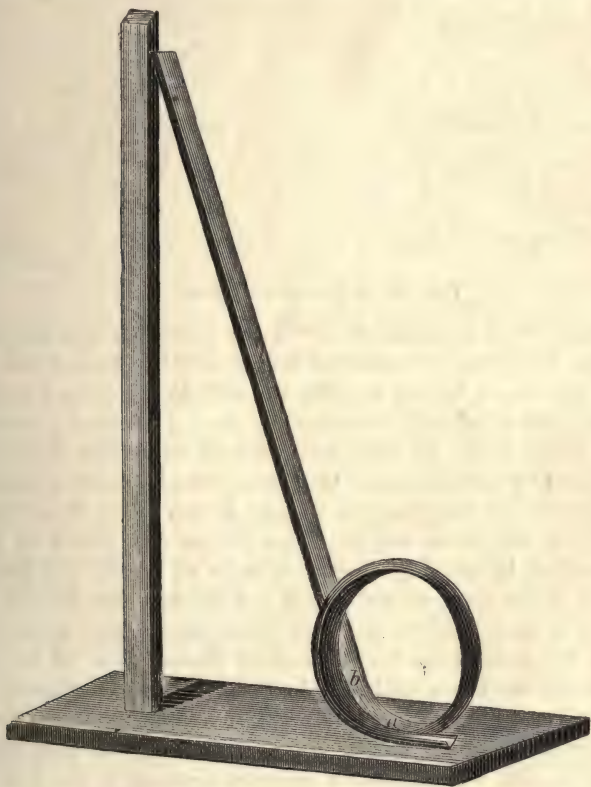


FIG. 105 (*an. proj.* $\frac{1}{6}$ real size).

tends to move with this velocity in a tangential direction, in virtue of its inertia; but being impelled to follow the curved path, it is pressed against the rail more strongly by centrifugal force than it is acted upon by gravity, so that even at the top of the spiral it will remain in contact with the rail.

The rail is made of thin cardboard. With a radius of 15^{cm} describe a circle, fig. 106*A*; divide the circle into four equal parts by the diameters $e d$, $f g$, perpendicular to one another; with the same radius, and g and d as centres, describe arcs intersecting in h ; join h and c , and the quadrant $d g$ will be bisected in i . Divide $i g$ into four equal parts with the compasses, and join the first point of division

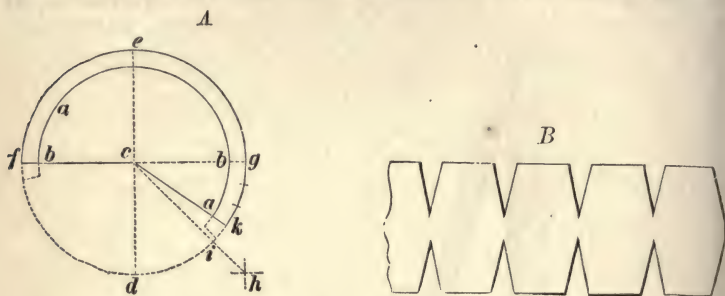


FIG. 106 (*A* $\frac{1}{10}$ real size; *B* real size).

k with c . With a radius of 13^{cm} and c as centre, describe the arc $a b a$. The piece of cardboard bounded by the lines of the figure, which are drawn in full, supplies one half of the curved portion of the rail; the other half is obtained by cutting a second piece exactly equal to the first. At both ends of each piece little flaps are left (indicated by dotted lines in the figure) which serve for connecting the curved and the straight portion of the rail. Both pieces of cardboard are placed flat upon one another and joined at the exterior edge, by glueing over it a strip of paper, not too stout, and cut in the form shown in fig. 106*B*; the glue should not be thin, or it runs between the two pieces and makes them adhere. When dry, press upon the two ends of the arc, so as to make them approach; the whole will open by itself and form a groove. Bend the whole more and more until it forms a spiral, $1\frac{3}{8}$ turn of a screw line; the letters a and b in fig. 105 correspond to the same letters in fig. 106. The two adjoining grooves between a and b are held together by glueing a strip of paper over the edges in contact. The two straight portions of the groove are made of two strips of cardboard, one 60^{cm} the other 6^{cm} long, and both 4^{cm} wide; the strips have a superficial line cut along their middle, both sides are bent towards each other, and along the bend a slip of paper is glued. Finally, the straight and curved portions are connected at the ends, the end of the long incline being glued upon the interior, the shorter portion upon the exterior sides of the curved path, lest the ball in rolling down should meet with any projecting edges;

the path will become still more unobstructed if the ends which are glued together are somewhat sharpened off at the edges.

At *a*, where the two parts of the groove adjoin, a piece of cork cut so as to fit into the triangular space between them and the board is pushed underneath and glued to the cardboard; the whole may then be fixed to the board by a stout pin stuck through the cork; the upper end of the groove may lean loosely on the upright or be fastened lightly by a pin or a tack.

17. *Molecular Constitution of Solids. Rigidity. Elasticity.*—It has been stated already, in art. 4, that the cause of the resistance which solid bodies offer to the separation of their particles is termed *cohesion*. Cohesion is an attractive force, acting between the ultimate molecules of a solid body; but it differs from other attractive forces—for example, the force of gravitation—in this respect, that while gravity acts between bodies at all distances, cohesion acts only when the distance between the particles is exceedingly small. The pieces into which a body may be broken up by any external force will not again cohere if placed in contact. The molecules have undergone a certain amount of mutual displacement by the action of the external force, and cannot again be brought so close together as they were previously; they cannot again be brought under the influence of cohesion, which acts between molecule and molecule at an indefinitely small distance only: the body remains therefore divided. There are other forces, besides cohesion, which act only between molecules at indefinitely small distances, and are hence termed *molecular forces*; such are *elasticity* and *adhesion*.

The resistance opposed by the molecules of a solid body to any external force which tends to overcome their cohesion, is also called the *rigidity* of a body. The rigidity depends on the manner in which the external

force acts upon the body; the resistance offered by the same body to forces which tend to elongate it until its particles separate, differs from that presented to forces which tend to bend it until it breaks: the former is the *absolute rigidity*, the latter the *flexural rigidity* of a body. Another kind of rigidity is termed the *hardness* of a body. Hardness signifies the resistance offered by a body when we attempt to cut or scratch it by another body. The finger easily enters a lump of moist clay; hence the clay is less hard, or softer than the finger. If the clay is dry, the finger can no longer penetrate into its substance: the clay is now harder than the finger. The relative hardness of bodies is usually compared by means of the following scale, in which the softest body is the first in the scale, while each succeeding substance is harder than the preceding one:—1. Talc (laminated variety); 2. Gypsum, or Rocksalt; 3. Calc spar; 4. Fluor spar; 5. Apatite; 6. Felspar, white crystalline (Orthoclase); 7. Quartz (Rock-crystal); 8. Topaz; 9. Sapphire (Corundum); 10. Diamond.¹

Bodies alter their form more or less under the action of an external force before they finally break. A fresh twig differs in this respect from a thin bar of dry wood; a piece of india-rubber or leather differs from hardened steel or a piece of slate, a hot bar of wrought iron from a bar of glass: bodies are called flexible, tenacious, ductile, etc., to indicate that they permit great changes of form without breaking; while others which are more apt to break are called brittle.

¹ In the above scale each mineral is *scratched by* the one that follows it and *scratches* the one before it. The hardness of any mineral may be determined by reference to these types; thus a piece of galena is scratched by calc spar and scratches gypsum, hence its hardness is 2·5.

Bodies the form of which has thus been changed by an external force tend in a greater or less degree to recover their previous form if the force ceases to act. A wire of lead, about 1^m long and 1^{mm} thick may be stretched by the hand so as to increase its length by a few centimetres, and if left to itself, it will not return to its former length. A copper or brass wire, after being made red-hot and cooled, may be bent into any shape; but a brass wire which has been hardened by hammering will, if bent, tend to return to its previous form. Bodies which tend to recover their form and dimensions, when these are forcibly changed, are called *elastic*; the property itself is called *elasticity*. India-rubber and watch-spring are examples of highly elastic bodies. Glass cannot be much altered in form without breaking, it is therefore called *brittle*; but if not broken, it immediately recovers its previous form, when left to itself; brittleness and elasticity are therefore by no means opposite properties, but a body may possess both at the same time. The elasticity of glass is well shown by a narrow long strip of window-glass, but much better by a spiral cut in the form of a spring, out of a glass cylinder. Such a spiral, fig. 107, may be pulled at both ends with thumb and forefinger, and the single coils will separate as far as 2^{mm} from one another without breaking; if the strain ceases, they close again completely together.

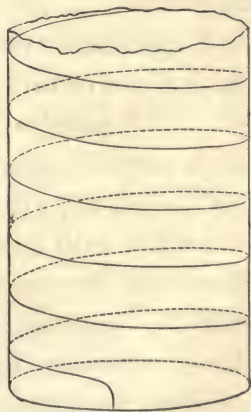


FIG. 107 (*an. proj.*
 $\frac{4}{5}$ real size).

The spiral is best cut from a wide cylinder. One end of a piece

of thread is fixed with a small piece of wax to the top of the cylinder, and wound round like a screw-line, the threads being at a distance of about 1^{cm} from one another; the other end of the thread is fixed to the bottom of the cylinder. A line is then drawn with pen and ink in the middle between the lines of the thread, forming another screw-line round the cylinder. When the ink is dry, the thread is removed; a scratch of the file is made at the edge of the cylinder, and a crack is led with a pastille all along the inked lines; or better still, the spiral may be cut between these in the place previously occupied by the thread, for the crack cannot be well seen upon the ink. The glass should be quite dry, and the pen dipped but little into the ink, or the ink will run. It is not easy to carry the crack right through from one end of the cylinder to the other; but this is not necessary for our purpose.

18. *Adhesion*.—In the preceding article it has been stated, that if once cohesion is destroyed the particle will not again manifest mutual attraction if brought in contact. Nevertheless, if the surfaces of two bodies be prepared in a manner which permits their close contact if placed one upon another, mutual attraction will manifest itself which may even cause the surfaces to stick together. This kind of attraction is called *Adhesion*.

Experiments on the force of adhesion are best made with plates of various substances, as marble, glass, metal etc., with polished and perfectly flat surfaces. If two such surfaces, after being carefully cleaned from dust be placed upon one another by sliding one plate over the other with a gentle pressure, a certain amount of force will be necessary to separate them, and this force will be greater the flatter the surfaces are, that is the greater the number of points at which they are in close contact. If such plates are very accurately polished and planed, a very considerable force will be required for their separation, while even such compar-

tively rough surfaces as those obtained by cutting two leaden cylinders, such as those described below (p. 158), with a penknife, so as to form two even and bright surfaces, will, if pressed and turned against each other until they are in close contact, adhere so strongly as to require a force of more than 100^{gr} to separate them. If plates of different substances—for example, glass and brass—are placed in contact, they will be found to manifest adhesion as well as plates of the same substance—for example, glass and glass.

Various modes of joining bodies are based upon the force of adhesion. Glass plates may be rendered so perfectly even by skilful workmen, that they cannot be again separated, if once in contact, without breaking. But in most cases a better contact is ensured by bringing some liquid or soft substances between the surfaces to be joined; after drying, the interposed substance is nearly everywhere in contact with both surfaces, and the separation cannot be effected without considerable force. The processes of glueing, pasting, soldering, &c., are such applications of the force of adhesion.

Plates of glass well adapted for experiments on adhesion may be prepared with some little trouble and patience; such plates will so be found to be very useful in the experiments on the pressure of water upon the sides of vessels, and it is therefore well worth while to devote some time to their preparation. Procure two circular discs of plate, or very flat window glass, 6^{cm} in diameter. They may be cut circular either by a pair of compasses which have a small diamond fixed at one point, or with the help of a lathe. Cut a circular disc of paper of the required size, place the glass upon it, and draw the outline of the circle with ink upon the glass. When the ink is dry commence a crack from the edge of the plate, and lead it along the circular line for some distance. Then begin a new crack from another point of the edge, as shown in fig. 13, and break away cautiously any pieces that can be removed.

Should a projecting corner remain anywhere, as in fig. 109, remove it with the flat pliers, by carefully breaking off little pieces of glass, one after another, each not larger than about a millimetre. The edges of the discs are then smoothed and rounded off upon a grinding stone, one person turning it, and another holding the edge of the disc upon it, taking care to change often the points in contact with the stone, lest angles or curves should be produced. The whole breadth of the stone should be used successively for grinding, or grooves will be produced in it, which render the stone useless.

The plates are polished by being ground upon each other with emery powder. One plate is fixed upon a small wooden board by driving three or four wire-pins into the wood, so placed that the plate rests

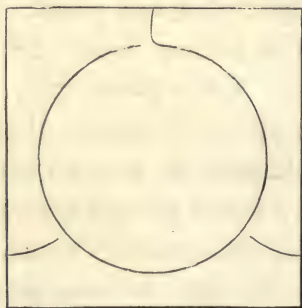


FIG. 108 ($\frac{1}{2}$ real size).

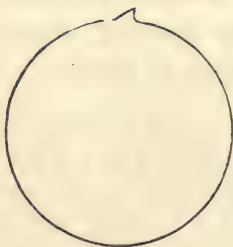


FIG. 109 ($\frac{1}{2}$ real size).

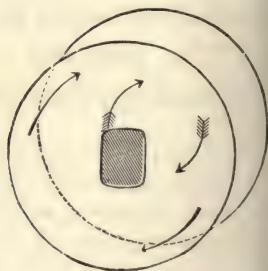


FIG. 110 ($\frac{1}{2}$ real size).

securely between them. The other plate is provided with a handle consisting of a piece of stout sealing-wax, 2.5 or 3^{cm} long, which is fixed to it by heating the plate cautiously over the lamp, and pressing the sealing-wax upon the heated plate. Sealing-wax will not adhere to metal or glass unless the latter substances are heated to the melting point of the sealing-wax. A small portion of emery is placed upon the fixed plate with a few drops of water. The moveable plate is moved upon the fixed plate with moderate friction, being turned

the same time round its own centre and round the centre of the fixed plate, so that it always projects somewhat over the edge of the latter, as shown in fig. 110, where the two pairs of arrows indicate the two rotatory motions of the plate. The grinding is continued, with occasional additions of emery and water, until both plates present everywhere a dull surface. They are then washed and dried, and the fixed plate rubbed over with a drop of oil and a little red lead (minium), until it appears uniformly coloured red. If the second plate is now placed upon the other, and moved just the smallest distance, it should appear also uniformly coloured red all over, if the plates are already evenly ground. If only scattered places appear coloured, the grinding must be continued; if the plates touch only in the middle, it is necessary to describe a smaller circle with the moveable plate, while the grinding is continued; but if the plates touch along the edges, and the central parts are thus hollow, it may arise from a small flexure of the thin glass in consequence of the pressure upon the handle, and in continuing the work the plate should not be moved by the handle, but by placing the points of the fingers along the edge and describing now a larger circle. When the plate takes the colour uniformly, but not before, a finer kind of emery is used for grinding; the surfaces will thereby lose a certain amount of roughness and become more plane. Gradually—repeating from time to time the test with oil and red lead—finer and finer kinds of emery are employed, altogether about four sorts of various degrees of fineness. Finally—when the plates already manifest a certain amount of adhesion, and after being washed and dried they exhibit a small degree of polish, so as to reflect slightly the image of a window sash or a lamp flame—they are polished with ‘jeweller’s rouge’ (an oxide of iron), which is used in the same manner as the emery; but in using the finer sorts of the latter and the rouge, very little water must be added, and the grinding always continued until the mass is almost dry.

The operation of grinding requires about two hours; if not successful with the first pair, attempt another. Good plates will adhere not only in a horizontal but also in a vertical position, one plate being held by the handle of sealing-wax.

In order to show the adhesion between different substances, prepare a plate of plaster of Paris. This substance mixed with water may be poured upon one of the polished glass plates. After a couple of hours the plate of plaster may be removed from the glass, and in a day it will be perfectly dry. The adhesion manifested by it is not very considerable, but sufficient to maintain it horizontal, if in contact with the glass plate, for about a second.

Prepare a paper mould, and form two leaden cylinders, 1^{cm} thick and about 1^{cm}·5 high. Cut a flat face upon each with a pen-knife until they are quite bright; place the faces together, and bring the whole between the cheeks of the vice. Apply pressure until the length of both cylinders is reduced to about one half the original length; the faces in contact will adhere with considerable force.

Fresh-cut surfaces of india-rubber manifest strong adhesion. a tube of black india-rubber be cut with the scissors, both ends usually closed by the adhesion of the cut edges, and must be opened by a slight pressure of the fingers. If, without touching the cut surfaces, these be placed in contact again, they will adhere, and thus left in contact for some time, the separated parts will remain joined pretty firmly.

2. *Hydrostatics and Hydrodynamics, or, the Equilibrium and Motion of Liquid Bodies.*

19. *Surface of Liquids. Transmission of Pressure in vessels.*—The molecules of a liquid body possess very little cohesion, and are displaced from their mutual positions by the smallest force. The shape of a liquid is therefore easily altered; it is general that of the vessel in which it happens to be placed. Being acted on by gravity, the liquid occupies first the lowest parts of the vessel, which it fills either completely or partially, presenting in any case a free surface which is a horizontal plane, when the liquid is at rest; this fact is usually expressed by saying: the surface of still water is *level*.

If a small stone or a leaden bullet is suspended by a string from the retort-stand or the frame in fig. 2, and allowed to plunge into a basin of water, slightly blackened with ink, the image of the thread produced by reflection at the surface of the liquid will be observed to be exactly in a straight line with the thread.

itself. This cannot happen, as will be seen subsequently, unless the surface of the water is at right angles with the thread. But the direction of the thread is vertical, and the direction perpendicular to it is horizontal: the surface of the liquid is hence horizontal.¹

It follows from the action of gravity upon a liquid which occupies only part of a vessel, that the unoccupied space will be above the surface of the liquid, that is, in

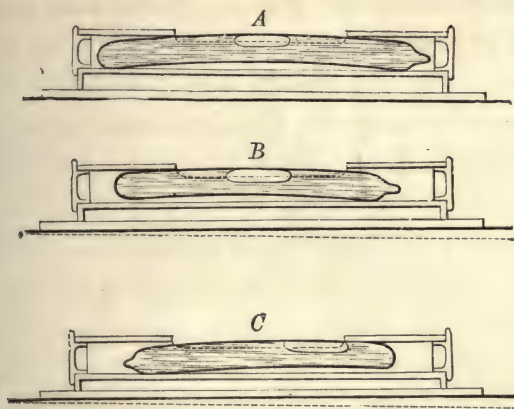


FIG. 111 ($\frac{1}{3}$ real size).

the highest part of the vessel, whatever position the latter may assume. This fact is applied in instruments employed for determining a line or surface which is perfectly level or horizontal. These instruments are called *levels*; figure 111 represents a section of a kind of level, usually called a spirit-level, in three different positions. The spirit-level consists of a glass tube very slightly curved, filled with spirit with the exception of a small space containing air which tends to occupy the highest part. This tube is placed in an outer tube of brass

¹The surface of a liquid is generally not horizontal where it is in contact with the vessel. This exception from the law will be considered in art. 23.

which has an aperture in the middle of the upper side, and when the instrument is in a perfectly horizontal position the bubble of air is exactly in the middle of the aperture; the exact position of the bubble in that case being usually marked by lines etched upon the glass tube. The brass tube is fixed upon a straight ruler of brass or iron. In determining a horizontal line one end of the level is raised or lowered until the bubble is in the middle, as shown in fig. 111 *A*. But it may happen, as in the case shown at *B*, that the level itself is not perfectly adjusted, and that the bubble is in the middle, although the line is not horizontal. This error may be recognised by reversing the level, so that the end which was before



FIG. 112 ($\frac{1}{2}$ real size).

on the right side may now be on the left: if the level is correct, the bubble will settle in the middle as before; but if not, it will move to the side which is highest, as shown in *C*. Good levels are usually provided with screws for correcting this error by raising or lowering permanently one end of the level. Another form of level is shown in fig. 112. It consists of a flat box of brass, with plane sides; the top is of glass, flat outside but concave inside, the radius of the concave surface being from $0^m\cdot5$ to 1^m , while in the spirit-levels previously described the tube forms an arc of a circle of which the diameter varies from 2 to 10^m . A hole closed by the screw *s* serves for filling the level with spirit.

A level determines only the horizontality of a line ; a surface cannot be said to be horizontal unless the level has always the bubble in the centre, in whatever position the instrument may be placed upon the surface.

When pressure is applied at the upper side of a book lying on the table, or at one end of a stick the other end of which rests upon the ground, the pressure is transmitted through the book and along the stick ; and if we leave out of consideration the weight of these bodies, we may say that the table or the ground has to bear the pressure which is applied to the book or the stick. A mass which consists of a soft substance or of small loose particles behaves somewhat differently. When pressure is applied to a lump of moist clay, which lies on the table, the pressure will also be transmitted to the table, but the particles of the body will at the same time be pressed laterally, and the lump of clay will become flattened. If a mass of flour or sand, contained in a paper or linen bag, be strongly pressed while it rests upon the table, there will be the same lateral pressure of the particles ; and if it be sufficiently great, the bag will burst at the sides. In a liquid the ultimate particles, having very little mutual cohesion, manifest this lateral pressure in the most perfect manner.

Pressure applied to a liquid is transmitted in all directions equally, that is, equal surfaces bear equal pressure. If a bottle filled with any liquid be closed with a tight-fitting cork, so that no space is left between the cork and the liquid, a moderate blow upon the cork may burst the bottle. The pressure upon the cork is transmitted in such a manner that each portion of the interior sur-

face of the bottle which has the same dimensions as the cork, has to bear the same pressure as that which is applied to the cork. In a common wine-bottle the area of a section of the neck, and hence of the cork, is about 3 square centimetres, and the internal surface of the bottle about 450 square centimetres. This surface contains therefore $\frac{450}{3} = 150$ surfaces, each equal to that of the cork, and has to bear a pressure 150 times as great. This fact may also be expressed thus :—

Pressure is transmitted in a liquid in such a manner that the pressures exerted upon different surfaces are proportional to the areas of the surfaces.

The *hydraulic press* is an application of the law of the transmission of pressure in liquids. Two hollow cylinders of different diameters, c and C , fig. 113, are connected by a tube r ; in each cylinder a solid piston moves water-tight. The smaller piston, or plunger, may be pressed down with the hand or by means of a special lever; the larger piston, or ram, S , carries a cast-iron plate, P_1 ; any body placed on this can be pressed against a second plate, P_2 , supported by strong columns. The portion of both cylinders below the pistons being filled with water, the pressure applied in a downward direction to the plunger is transmitted to the ram, and forces it upwards. If the diameters of the pistons be 2 and 20^{cm}, their sections are $1 \times 1 \times 3.14 = 3.14$ ^{cm}, and $10 \times 10 \times 3.14 = 314$ ^{cm} respectively, and the pressure upon the ram is $\frac{314}{3.14} = 100$ times as great as that upon the plunger. Thus a pressure of 50^{kg} upon the plunger produces a Pressure of 5,000^{kg} upon the ram.

That the principle of the equality of work holds here also, may be easily shown. In order to raise the ram through $1^{\text{cm}} = 0^{\text{m}}\cdot 01$, 314^{cc} of water must be pressed into the larger cylinder; to do this, since the smaller piston has a section of $3^{\text{cm}}\cdot 14$, it will be necessary to press it downwards through $100^{\text{cm}} = 1^{\text{m}}$. The work done by the ram, supposing the pressures to be equal to

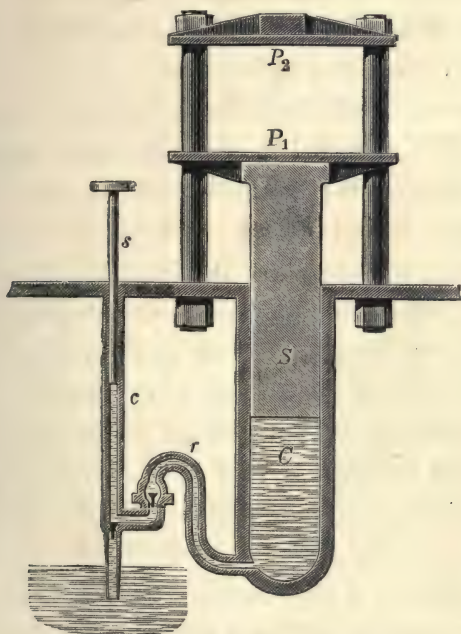


FIG. 113 ($\frac{1}{20}$ real size).

hose above mentioned, is $5,000^{\text{kg}} \times 0^{\text{m}}\cdot 01 = 50$ kilogrammetres, and the work done upon the plunger is $0^{\text{kg}} \times 1^{\text{m}} = 50$ kilogrammetres, or the same as that one by the ram.

It would follow from this that in order to raise the ram $0^{\text{m}}\cdot 5$ by a single stroke of the plunger, the latter would have to descend through 50^{m} ; such a length of

the smaller cylinder is however obviously impracticable and the smaller cylinder is therefore constructed like a pump, so that the required quantity of water can be pressed into the larger cylinder by a number of successive comparatively short strokes of the plunger. The essential parts of this contrivance are indicated in fig. 113, but cannot be explained until a subsequent part of this work; nor is it possible to enter here more fully upon the various details which must be attended to in the construction of a hydraulic press.

The pressure which we have hitherto considered has been applied externally, and has been equally transmitted through the mass of the liquid. But liquids have weight, that is, they are acted on by gravity like other bodies, and hence it is evident not only that the upper portions of a liquid mass press upon those below but also that the pressure at any point is greater the deeper it is below the surface of the liquid.

The pressure is the same at all points which have equal depths below the surface, that is, at all points of the same horizontal layer; and at different depths the pressure is proportional to the depth.

This pressure is also transmitted equally in all directions, although caused by a force which acts vertically. Each particle which is pressed is from the nature of a liquid capable of moving in any direction, hence *In order that a liquid may remain at rest, each molecule of the mass must be subject in every direction to equal and contrary pressures.* Whenever the pressure upon a molecule in one direction is greater than that in another, the molecule will move.

In order to investigate the pressure which liquids exert by their weight upon the horizontal bottom of

vessel, let fig. 114 represent a vessel with vertical sides, which has been placed empty in one scale-pan of a balance and counterpoised by weights placed in the other scale-pan. It is evident that if 100^{gr} of water be now poured into the vessel, weights amounting to 100 grammes will have to be placed in the opposite scale-pan, in order to restore equilibrium; this will hold good, whatever be the weight of the liquid which is poured into the vessel—an equal weight must always be placed in the opposite scale-pan to produce equilibrium. For although the liquid presses not only on the bottom of the vessel, but also against the sides, so that if they were moveable it would force them outwards, still

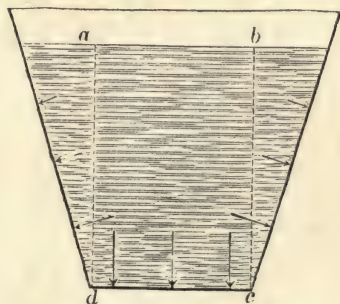
FIG. 114 ($\frac{1}{2}$ real size).

FIG. 115.

the total horizontal pressure upon any one side is neutralised by an equal and contrary pressure upon the opposite side; for although the pressure increases with the depth (as indicated by the arrows in the figure), it is the same at all points of each horizontal layer. Hence the only pressure that can take effect externally is the downward pressure upon the bottom of the vessel, and therefore, *in a vessel with perpendicular sides the pressure upon the base is equal to the weight of the contained liquid.*

In a vessel which is wider at the top than at the bottom, fig. 115, the lateral pressure acting perpendicularly to the sides, as indicated by the arrows, is not horizontal, and the pressure at two opposite points in the same horizontal layer is therefore not exactly opposite, but at both sides it is directed downwards, tending to press the sides down, not directly asunder; consequently, both sides and base have to bear a downward pressure. The total downward pressure must obviously in this case also be equal to the weight of the liquid, but part of it is borne by the sides, and it follows that, *in a vessel which becomes gradually narrower towards the base, the pressure upon the bottom is less than the weight of the contained liquid.* The pressure upon the bottom of the vessel represented in fig. 115 is equal to the weight of the liquid column $a b d c$, that is, it is the same as that upon the bottom of the vessel in fig. 114, if the area of the base and the depth of liquid are the same in both vessels, and the liquids are also the same.

If the sides of a vessel be inclined inwards, as in fig. 116, the lateral pressure is directed outwards and upwards: the sides are pressed away from each other, but at the same time in a manner which would separate them from the base, in an upward direction, if they could move freely. Whatever the weight of the liquid in the vessel, that will also

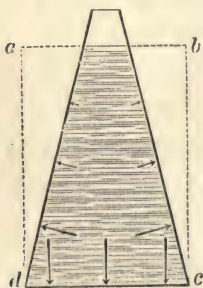


FIG. 116 ($\frac{1}{2}$ real size).

be the force with which the bottom presses against the scale-pan. But this cannot be the whole pressure upon the base, for the pressure transmitted to the scale-pan

As the pressure upon the base, diminished by the upward pressure of the liquid against the sides, which tends to lift the sides from the bottom of the vessel. If therefore the pressure of the liquid upon the base, diminished by the upward pressure, is still equal to the weight of the liquid, it follows that, *in a vessel which becomes gradually wider towards the base, the pressure upon the bottom is greater than the weight of the contained liquid.*

For experiments on the pressure of liquids vessels with a moveable bottom are required. They may be prepared from lamp cylinders the glass of which is not too thin. In such a cylinder, fig. 117 A, three rather deep notches *a*, *b*, *c*, running all round, are made with the three-cornered file; a burning pastille is held at a point of the notch

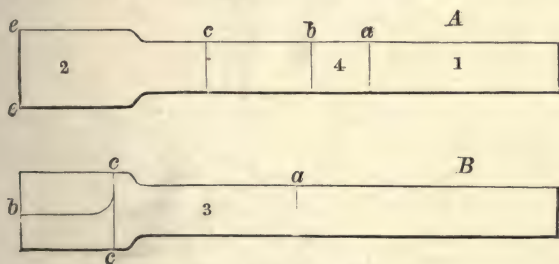
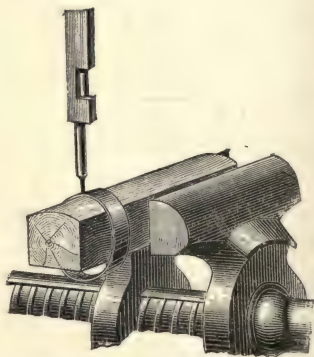


FIG. 117 ($\frac{1}{4}$ real size).

until a crack is produced, which is then carried all round. In a second cylinder, fig. 117 B, the notch is only made all round at *a*, while at *b* only a short notch is made at the edge, and the crack carried along the line indicated, and from *c* to *c* all round the cylinder. This is necessary because it is scarcely possible to carry a crack in a direct line all round *c c*, so near to the place where the cylinder becomes narrower. The cylinders marked 1, 2, 3, are to be well ground at one end—1 at *a*, 2 at *c*, 3 at *c c*, so as to fit closely when placed upon the plates used for the experiments on adhesion—the one marked 4 must be carefully ground well at both ends. Select a piece of window or plate glass, as even as possible, place it horizontal and grind with emery and a little water, moving the cylinder round in a small circle and turning them at the same time. Begin with rough emery and use about three sorts, ending with the finest. This will be quite sufficient to prevent the escape of water, if the cleaned edge of the cylinder is placed upon the adhesion plate, and the

liquid poured in the vessel; at most a few drops will escape very slowly, and nothing whatever if the edge of the cylinder be very slightly rubbed over with a drop of oil. Cylinder 3 requires a little more pressure than the others to make it adhere. The cylinders 1 and 2 must now be provided at their upper end with metal collars, 1^{cm} wide. Cut a strip of sheet zinc or brass, so thin that it may be cut with the scissors, and make it about $3\frac{1}{2}$ times as long as the external diameter of the cylinder at the top. Bend it into a ring which slips easily over the cylinder, and solder the ends together; if zinc is used take care not to melt it, especially when heating it over a Bunsen's burner. Two holes are drilled in the ring, opposite to one another. The most convenient form of drill for such small holes is shown in fig. 118. To avoid bending the ring out of shape while marking the holes with the centre-punch and drilling them, the ring is placed

FIG. 118 (*real size*).FIG. 119 (*an. proj. $\frac{1}{3}$ real size*).

upon a rounded piece of wood, which is clamped horizontally between the cheeks of the vice, so as to project partly, as shown in fig. 119. The breastplate cannot in this case be pressed against the chest, but is held with the left hand, while the right moves the drill-bow. The holes must be nearer to one edge of the ring than to the other, as seen in fig. 120, which shows the vessels in the finished state. The upper rim of each vessel is now heated very cautiously over a lamp, turning the cylinder continually while heating, until sealing-wax melts upon it, and the rim is covered with a layer of it of about 1^{mm} in thickness; when the whole has cooled the ring is also heated to the temperature at which sealing-wax melts upon it, and pushed while hot over the rim, but only so far as to leave the holes free; the wax which has been squeezed out along the edge is scraped off, after it has cooled, with a knife. Handles of brass wire

are now attached to the holes of the ring; they are bent more than required, as shown in fig. 120, *a*, and will thus press firmly against the rings by their own elasticity. Into the top of the short cylinder, 4, a flat cork is fitted, which has a hole through the middle large enough to receive a glass tube with an internal diameter of about 1^{cm}; the tube is 6 or 7^{cm} long and fixed into the aperture with

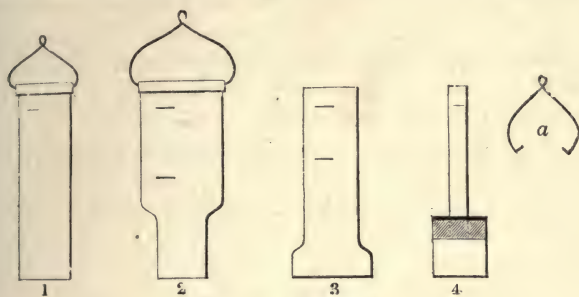


FIG. 120 ($\frac{1}{4}$ real size).

sealing-wax in the following manner. The cork is pressed down into the cylinder until the edge of the latter projects about 1^{mm}·5; in the depression thus formed sealing-wax is melted all round and made to adhere firmly to the glass. This last operation is best performed with the help of a blowpipe, which is used for directing the point of the flame of a spirit-lamp upon the sealing-wax, as shown in fig. 121.

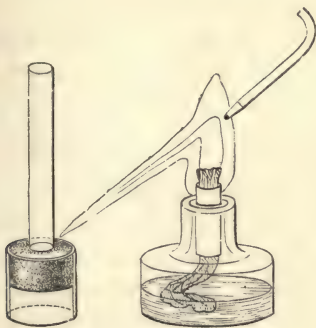


FIG. 121 (*an. proj.* $\frac{1}{3}$ real size).

The blowpipe is in its simplest form a conical tube of brass about 25^{cm} long, bent near one end, which has a fine aperture, while that of the other end is about 9^{mm} wide. The blowpipe may be used for the soldering of small objects or whenever great heat is required; in using it the air must be projected by the muscles, not of the

chest, but of the mouth, which should be blown out like a trumpeter's, while the breathing has to be carried on through the nose only. First practise without the blowpipe in the mouth, inflating the cheeks, and while inflated breathe through the nose; then, without opening the mouth, force the blowpipe between the lips, and it will be found that the escape of air from the blowpipe is so little that the process of breathing with inflated cheeks can be continued, and thus a steady flame procured. If the pointed end be held inside the flame, and a current of air be directed across it a little above the wick, the flame is thrown to one side in the form of a pointed cone. In the present case the only reason for using the blowpipe is to obtain a flame which is directed downwards; it is not necessary that the flame should be steady, but care must be taken not to crack the glass or char the sealing-wax by the excessive heat.

Since the plate which forms the bottom of the vessels will have to be suspended from the balance, a hole must be drilled through its centre, and widened to about 4^{mm}. Further, a screw is to be cut from end to end of a piece of brass wire, 7^{cm} long and from 3 to 4^{mm} thick, care being taken in cutting it to hold the die-stock perpendicular to the wire, or the nut which is to be used with the screw will not be horizontal. The wire must be straightened previously, and to avoid flattening it, this must be done with a wooden hammer upon a wooden support, after the wire has been made red-hot and allowed to cool. One extremity of the wire is filed flat on both sides, for a short distance, and a hole is drilled through the flattened end, through which a thread may be passed afterwards. Round the other end a small leaden weight is fixed, about 15^{mm} thick and 12^{mm} high, by inserting the end into the mould already described. While the lead is poured into the mould, the wire is kept in the proper position by fixing it in the fork of the retort-stand.

The nuts are made of brass, about 2^{mm}·5 thick. Two pieces, each about 10^{mm} square, are cut out of a sheet of brass with the help of a saw or a chisel. Fig. 122 shows a 'frame-saw,' which is usually

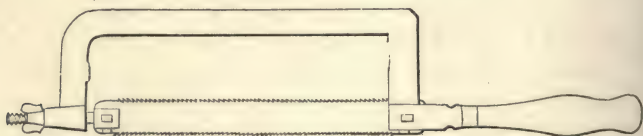


FIG. 122 ($\frac{1}{5}$ real size).

employed for cutting metal. The frame is made of iron, and forms three sides of a rectangle, of which the blade forms the fourth side. Two square pieces of iron, one at each end of the frame, are provided

with hooks in order to hold the blade; the piece near the handle is fixed, but the opposite piece is moveable by a screw and winged nut for the purpose of stretching the blade, and thus giving to it the required tension. A blade for sawing metal is thin, and the teeth are not *set* as is the case with a saw for wood, in which every alternate tooth is bent a little on one side and the intermediate teeth, to an equal extent, on the other side. The motion of a saw for metal is necessarily slow, and the 'kerf' or cut made by it is not wider than the thickness of the blade. The saw must be lubricated with oil or tallow-grease, when used.

Pieces may also be cut out of thick sheets of metal with the chisel, which is preferable on account of the facility with which this tool may be sharpened when it has become blunt, while it requires considerable trouble and time to sharpen a saw, as the blade has to be fixed in the vice and each tooth made sharp with a triangular file.

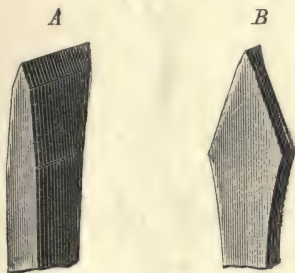


FIG. 123 (*an. proj. real size*).

The use of the chisel necessitates a very heavy support for the metal which is to be cut; if the vice weighs less than 10 or 12^{kg}, a large flat surface of stone such as the sandstone steps of a house, or an anvil, should be made use of. The sheet of metal is fixed in the vice, so that the line along which the cut is required is just above the edge of the cheeks; the chisel is placed horizontal upon the line and held with the left hand, while vigorous blows with the hammer upon the top of the chisel are given by the right hand. If a stone or anvil be used, the metal is cut through to about two-thirds of its thickness; the part to be broken off is then clamped in the vice, and the remainder of the sheet bent to and fro until the two portions are separated. On a support of wrought iron or lead the cut may even be carried through the whole thickness without endangering the chisel. The usual form of chisel is that in fig. 123 A, although for various purposes a smaller edge is preferable, as in the form shown in fig. 123 B.

The line along which a cut is to be made should be marked pre-

viously; this may be done with the point of the centre-punch or one of the corners of the chisel. The edge of the latter should be firmly placed upon the line before each blow is delivered; if this precaution is neglected, the edge is liable to break off. Since the chisel is apt to get out of the depression produced by the first blow, it must be firmly placed back again into it, before the next blow is given.

In sharpening a chisel which has become blunt, the chief point to attend to is to grind the surfaces flat and not rounded; for this purpose care must be taken to hold the tool in the same position while it is moved to and fro across the breadth of the revolving stone; if the chisel is kept on one part of the circumference of the

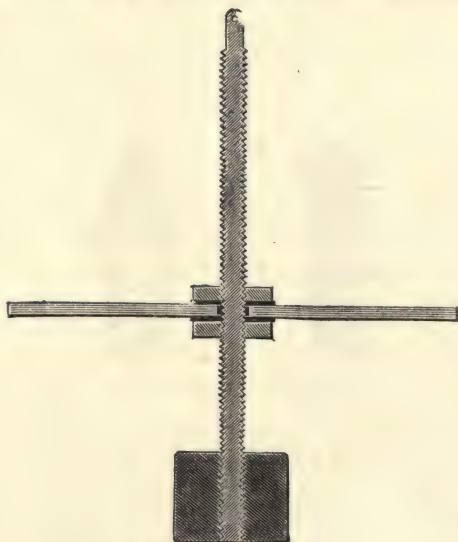


FIG. 124.

grindstone, the latter will be spoiled by grooves, and the corners of the chisel will become rounded instead of being sharp. The roughness of the edge, which remains after the grinding, must be removed upon the hone. If a piece has been broken out, the edge of the chisel may be restored by softening the metal, producing a new edge by the file, and tempering again, in the manner previously explained.

The two nuts should be bored quite straight through at the centre and the threads cut in them before the screw is prepared; one of them is filed accurately square, the other circular. The latter is screwed down until its distance from the leaden weight is 1^{cm}.5, and soldered on its lower side to the spindle; no solder must reach the

upper part of the spindle, or it will not admit the second nut. The glass plate, with its ground side uppermost, is placed between the nuts, but between it and the hard metallic surfaces of the nuts small discs of wash-leather are placed, which have been previously moistened with oil or greased with tallow. The leather discs prevent the escape of water between nuts and screw, and protect the glass plate, which without them would probably crack when the nuts are firmly screwed upon it. The object of the leaden weight at the bottom of the spindle is to make the plate hang exactly horizontal. A section of the whole arrangement is given in fig. 124.

A small scale-pan with short strings will complete the preparations for these experiments. It may be made of a small box such as has been mentioned when speaking of the experiments on the pulley. The bottom is pierced in the middle, for attaching a small hook of wire to it.

The vessels marked 1, 2, 3, in fig. 120, serve to show the effects of liquid pressure on the walls of vessels. The balance is suspended to the frame (fig. 35) by a hook screwed into the cross-bar, or by a piece of wire: a thread would allow lateral motion. The beam carries a common scale-pan at the right-hand extremity, and at the left a short pan with a hook, from which the vessel 1 is suspended with thread. Equilibrium is produced by sand or shot, and one of the unperforated glass plates, held in the fork of the retort-stand by the sealing-wax handle is brought under the cylinder. Care must be taken to place the plate in a perfectly horizontal position, so that it may touch all round the rim of the suspended vessel. The rim may now be slightly oiled, to prevent the escape of water, or the vessel may be pressed more closely against the plate by placing a small weight, not more than 5^{gr}, in the scale-pan above the vessel. The whole is shown in fig. 125.

A plate or basin is now placed below the vessel, and the latter filled with water, poured out of a small glass or a test-tube. That the vessel may be filled in this

manner, proves that the liquid exerts no upward pressure against the sides. That there is no downward pressure is shown by placing a weight in the scale-pan on the right-hand side; the cylinder will be immediately lifted from the plate and the water will escape. The weight necessary for this will be about 2 or 3^{gr}, if the rim has been oiled, and 7 or 8^{gr} if a weight of 5^{gr} was used on the left-hand side for pressing the cylinder against the plate. The vessel 2 is now balanced in the same manner; no oil or weight is required for preventing the

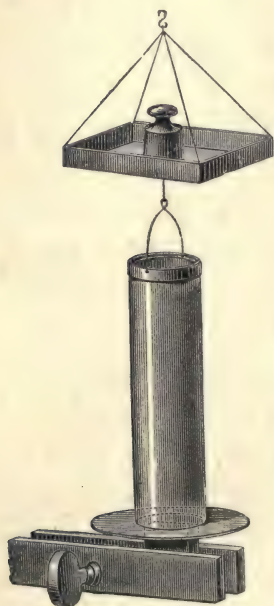


FIG. 125 (*an. proj.* $\frac{1}{3}$ *real size*).

escape of water; a light pressure with the hand, while the water is poured in, is sufficient. When full, the downward pressure of the water against the sides is so great that a weight of 20^{gr} or more may be placed in the scale-pan on the right without lifting the sides of the vessel from the base. The vessel 3 is not suspended, but simply placed upon the plate, against which it presses with its own weight. It can only be filled with water up to a certain height; if more water is added, the upward pressure of the liquid against the sides is sufficient to raise them above the plate, thus allowing the water to escape. In doing so the vessel tends to glide laterally from the plate. To prevent its falling and breaking, the left hand must be ready to seize it.

For the experiments on the pressure upon the base

of vessels it is necessary to mark upon the vessels 1, 2, and 3 the height to which they are filled by an equal quantity of water, namely, the quantity which nearly fills the vessel 1. This will generally be found to be about 40^{cc} , or 40^{gr} ; assuming, for illustration, that this is the quantity required, the vessels are to be placed successively upon the plate, 40^{gr} of water poured into each, and the position of the surface marked upon the glass by a scratch with a file, or by pasting on it a narrow strip of paper. Marks must also be placed on the vessels 2, 3, and 4 at the same height as the mark on vessel 1. These marks are shown in fig. 120, and they shall represent the height of 40^{gr} of water.

The prepared plate is now suspended from the left-hand arm of the balance by a thread and counterpoised. A small wire hook is attached to the thread, to facilitate the removal and suspension. The vessel 1 is then clamped in the fork of the retort-stand, the thread passed through it, hooked to the scale-pan, and the fork carefully adjusted until the rim of the cylinder everywhere touches the plate, and the small brass rod is exactly in the middle of the cylinder, as shown in fig. 126. The plate is now drawn

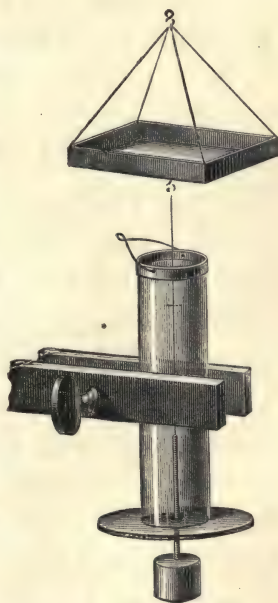


FIG. 126 (*an. proj.* $\frac{1}{3}$ real size).

down, so that the lower rim of the cylinder may be slightly oiled, and brought again slowly and carefully into proper contact with the cylinder.

A weight of 40^{gr} being placed in the scale-pan, water is poured cautiously into the vessel, up to the mark. With proper care no water will escape. The weight of 40^{gr} in the scale-pan on the right hand balances the pressure of the water upon the base of the vessel; but if a very small quantity of water be added, the plate which represents the base will be pressed downwards by the additional weight, and the water will escape. The pressure of 40^{gr} of water upon the base is hence not less than 40^{gr}. In consequence of the escape of water, drops will attach themselves to the plate and the other portions of the apparatus; these must be carefully removed before the next experiment is commenced, since they interfere with the correct estimation of the weights which are really employed.

When the same quantity of water is now poured into vessel 2, which may be fixed in the manner described further on, it will be found that 40^{gr} of water do not in this case exert a pressure of 40^{gr} upon the base of the vessel. The pressure is less, for a quantity of water may be added considerably exceeding the height of the mark, but the plate is not pressed down, and no water escapes. This will not happen until the height of the water in vessel 2 is exactly the same as that which it had in vessel 1, when the water commenced to escape. This shows, not only that the pressure upon the base of a vessel which gradually widens from the base towards the top is less than the weight of the contained liquid, but also that the pressure is the same as that upon the base of a vessel with perpendicular sides, when the area of the base and the height of the liquid are equal in both vessels. When vessel 3 is used, the

plate will be pressed down before the whole quantity of 40^{gr} is poured into it; this proves at once that in a vessel which becomes gradually narrower from the bottom towards the top, the pressure upon the base is greater than the weight of the contained liquid. This vessel, however, cannot be strictly compared with vessels 1 and 2, because it has a wider base. Vessel 4 is therefore finally used for the same experiment. It has not a sufficient capacity for holding 40^{gr} of water; but as the water will begin to escape from this vessel when it is filled up to the same height as that at which the water escaped from vessel 1, it proves that, in a vessel narrower at the top than at the base, the pressure upon the base is the same as that upon the base of a vessel with perpendicular sides, if the area of the base and the height of the liquid is the same in both vessels.

The upper part of vessel 2 is too wide, and the lower too short, for being clamped in the retort-stand. Therefore, in order to support, cut a thin strip of zinc, 2^{cm} wide and about five times as long as

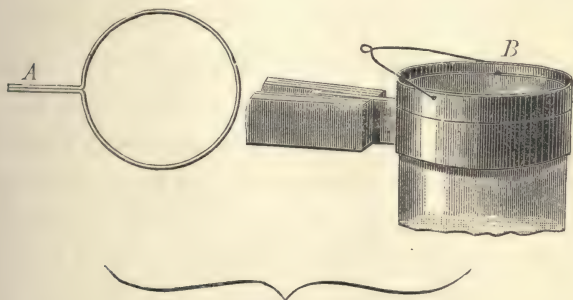


FIG. 127 ($\frac{1}{2}$ real size; B, an. proj.).

the diameter of the wide part of the vessel; bend it into the form shown at A, fig. 127, solder the two straight parts together to make a handle which can be clamped in the fork of the retort-stand, and suspend the vessel in the ring in the manner shown at B.

The pressure upon the bottom of vessels, as the preceding experiments have demonstrated, is independent of the form of the vessels : it is solely dependent on the area of the base, on the perpendicular height of the surface of the liquid above the base, and also, as is evident, on the nature of the liquid. The pressure is always equal to the weight of a liquid column with vertical sides standing upon a horizontal base, and it is quite immaterial whether the actual weight of the liquid is greater or less than such a column, as is respectively the case in vessels wider or narrower at the top than at the base. The pressure upon the base of a vessel can consequently be easily calculated. The volume of a straight column is found by multiplying the area of the base into the vertical height. If the liquid is water, the number of cubic centimetres in the volume equals the number of grammes in the weight with which the liquid presses upon the base, because 1^{cc} of water weighs 1^{gr}. If the liquid is not water, its specific gravity must be determined in order to know how much heavier or lighter a unit-volume of it is than an equal volume of water, and the pressure of the liquid is then found by multiplying its specific gravity into the pressure which an equal column of water would exert upon the same base.

For example, let it be required to find the pressure exerted by a solution of common salt, which has a specific gravity of 1.2, and fills a rectangular vessel 10^{cm} long, 8^{cm} wide, and 6^{cm} high upon the base. The area of the base is $10 \times 8 = 80$ square centimetres ; hence the volume of the whole liquid $80 \times 6 = 480^{\text{cc}}$. If the liquid were water, the pressure would be 480^{gr} ; but, as

the solution of salt is 1.2 times as heavy, the pressure is $480 \times 1.2 = 576^{\text{gr.}}$

In general, then, the pressure, expressed in grammes, upon the horizontal base of a vessel containing a liquid is found by multiplying the number of square centimetres in the area of the base into the perpendicular height of the liquid in the vessel, and into the specific gravity of the liquid.

20. *Communicating Vessels. Buoyancy. Principle of Archimedes.*—It has been already stated that the pressure at any point in a liquid at rest is the same in every direction. Hence any surface of which the lower

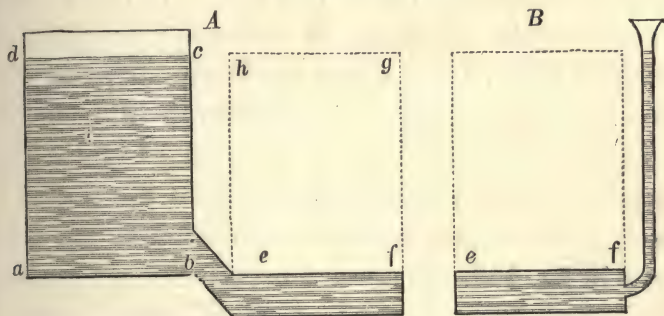


FIG. 128.

side is in contact with a liquid is pressed upwards with the same force with which an equal surface is pressed downwards, of which the upper side is in contact with the liquid, provided that both surfaces are at the same depth below the top of the liquid. If a vessel have the form fig. 128, A, ef and ab being equal and in the same horizontal plane, the upward pressure upon the surface ef will be equal to the downward pressure upon the surface ab , for in both cases it is equal to the weight of the liquid column $abcd$, or to that of an equal

column $efgh$ which may be supposed to exist above ef . Again, the pressure upon ef , in fig. 128, B , is equal to the pressure upon ef in fig. 128, A , if the areas pressed upon and their depths below the top of the liquid are supposed to be equal, and the upward pressure may be calculated on the same principles as the downward pressure. It follows at once that in a vessel of the form fig. 128, B , or one similar to it, the pressure upon the surface ef , which is equal to the weight of the liquid column $efgh$, may be much greater than the weight of the liquid actually contained in the vessel.

The upward pressure in a liquid may be shown by means of the glass plate represented in fig. 124. A string is attached to the upper end, and passed through the vessel 3 (fig. 120), which is almost completely immersed in a rather large jar of water, holding it with the left hand while the string is stretched by the right hand and the plate thus pressed against the rim of the vessel. When the vessel is immersed to the depth shown in fig. 129, the upward pressure of the water is sufficient to keep the plate from falling though the string be let go, the size of the plate and other parts of the apparatus being supposed to be those specified previously. If the leaden weight has been made too large, and hence the plate too heavy, the weight may be diminished by cutting away a portion of the lead with a knife.

By means of the *Hydrostatic Bellows* (fig. 130), a small quantity of water is made to produce considerable upward pressure. It is composed of two flat circular boards united at the sides by flexible leather so as to form a vessel, into the side of which is fixed an upright

tube, 1 or 2^{cm} wide, which is bent into a right angle at the lower end. If water be poured into the tube, it will fill the cavity of the vessel and separate the boards, and by adding more water the instrument may be made to support a very considerable weight. Thus, suppose the upper board to have a diameter of 20^{cm}, that is, a

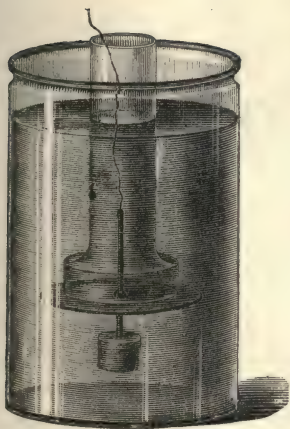


FIG. 129 (*an. proj.* $\frac{1}{3}$ real size).

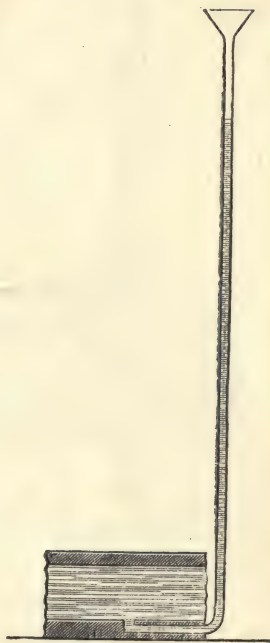


FIG. 130 ($\frac{1}{10}$ real size).

radius of 10^{cm}, and hence a superficial area of $10 \times 10 \times 3.14 = 314$ square centimetres, and the surface of the water in the tube to be 50^{cm} higher than the lower side of the board, then the pressure upon this side which tends to raise the board is equal to a weight of $314 \times 50 = 15,700^{\text{cc}}$ of water, that is, of 15,700 grammes, or 15^{kgr.}7.

The construction of the hydrostatic bellows is not quite easy, but the apparatus shown in fig. 131 may be employed for the same purpose.

A pig's bladder, or, better still, that of an ox, is cut down near its mouth so far that the end of a glass tube of about the thickness of a finger, and 10^{cm} in length, may be passed through the aperture and



FIG. 131 (*an. proj.* $\frac{1}{12}$ real size).

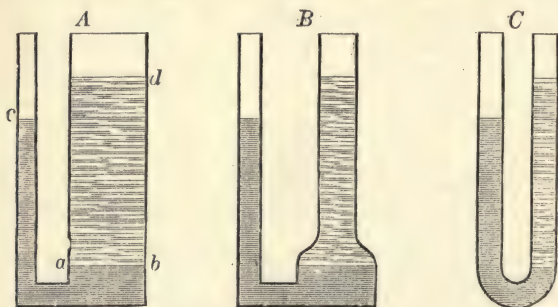
firmly tied (if necessary with the help of a cork, as described on page 14). A longer glass tube (about 70^{cm}) is connected with the shorter by a piece of tight-fitting india-rubber tube, and held in a vertical position by the fork of the retort-stand. The bladder is moistened, placed upon the table, flattened out as much as possible, and a piece of board, such as the lid of a box, or a drawing-board, laid upon it, so that the bladder is not in the middle but close to the edge of the board, as seen at *B* in the figure. At each end of the bladder small blocks of wood, *KK*, about 2 or 3^{cm} high, are placed, in order to protect the glass tube, which reaches under the board, from being broken by the pressure of the board and the weights to be afterwards placed upon it. By pouring water from a bottle or through a funnel into the tube the bladder is filled until the board begins to rise above the blocks and is in contact with the table only along the edge *ab*.

The weights must not be placed over the middle of the bladder, but nearer to the edge ab , as otherwise they might fall over and break the glass tube, especially if they are heavy and are raised to a considerable height. When the weights are placed upon the board it is pressed down until it touches the small blocks; the water in the tube R will in consequence rise somewhat, and if more water be poured in, the board with the weights upon it will be again gradually raised. If a pig's bladder is used, several kilogrammes may be raised in this manner; with an ox-bladder from 40 to 50 kg , and if the water in the tube R is about 1^{m} high a man may be raised. A large stone or any other heavy object may be used instead of weights. It is obvious, without weighing, that the raised weight is much larger than the weight of the water used. When the experiment is finished, the upright tube is unclamped, bent downwards at one side, and the water is allowed to run into a vessel placed underneath.

The raising of a large weight by means of a small quantity of water is another illustration of the previous statements concerning mechanical work. The water which is poured into the cavity of the bellows raises a considerable weight through a small space, but the work (force multiplied into space) thus performed is not greater than that which is performed by the small quantity of water which descends and traverses the much larger space represented by the height of the vertical tube.

Instead of weights, as in the hydrostatic bellows, we may employ the downward pressure of one liquid to counteract the upward pressure of another, and thus produce equilibrium. Fig. 132, A , represents two vessels communicating at their bases. The wider vessel has a sectional area of 300 square centimetres; the narrower vessel, on the left side, and the lower part of the wider, as far as ab , is filled with water, while the upper part of the wider vessel contains paraffin-oil, the specific gravity of which is 0.8. The perpendicular distance

between the horizontal plane $a b$ and c is 40^{cm} . The surface at which both liquids are in contact experiences from below an upward pressure, which is equal to the weight of a column of water, having a base of 300 square centimetres, and a height of 40^{cm} , that is, a pressure of $40 \times 300 = 12,000^{\text{cc}}$ water, or $12,000^{\text{gr}}$. Equilibrium can only exist if the surface of contact supports an equal downward pressure from above.

FIG. 132 ($\frac{1}{20}$ real size).

The volume of a column of paraffin-oil which weighs $12,000^{\text{gr}}$ is easily found, for its specific gravity being 0.8 , 1^{cc} of the oil weighs 0.8^{gr} , and therefore the number of cubic centimetres of it that are required to make up together a weight of $12,000^{\text{gr}}$ is equal to the number of times that 0.8 is contained in $12,000$, that is, we require $\frac{12,000}{0.8} = 15,000^{\text{cc}}$. The volume of the liquid column

and the area of its base being known, the height may be calculated; for the volume is the product of the area of the base into the height, and hence the height is found by dividing the volume by the base.

In our case it is $\frac{15,000}{300} = 50^{\text{cm}}$. The height of the

column of paraffin-oil above the surface of contact must therefore be 50^{cm} , in order to balance a column of water which has only a height of 40^{cm} , and the case would be precisely the same if the communicating vessels had different forms, for instance those of *B* or *C* in fig. 132; for the pressure upon the surface *a b* depends not on the form of the vessels, but solely upon the vertical heights *a c* and *b d*. It will be seen that the height of the column of water (40^{cm}) is contained in the height of the oil (50^{cm}) precisely as many times as the specific gravity of the paraffin-oil (0.8) is contained in the specific gravity of water (1). *The perpendicular heights measured from the common surface of contact of two liquid columns in communicating tubes are inversely proportional to the specific gravities of the liquids*; thus $40 : 50 :: 0.8 : 1$.

If both liquids have the same specific gravity, that is, if their specific gravities are in the ratio of $1 : 1$, the heights will clearly be also as $1 : 1$. The case of two different liquids having the same specific gravity is rare, but the result with reference to the heights will obviously be the same if, instead of two different liquids of equal specific gravity,

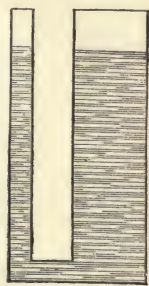


FIG. 133.

there is one and the same liquid in both tubes. Hence it follows that for the same liquid: *In communicating tubes a liquid rises to the same height.* This is shown in fig. 133.

In the preceding experiments the height of the liquid has been supposed to be independent of the internal width of the vessels; but this is not the case if the internal diameter of a vessel is less than 1^{cm} . In such vessels the height of a liquid is influenced by forces which

will be considered further on. The narrower vessel for these experiments must therefore be wider than 1^{cm}, and the internal diameter of the wider vessel should be considerably greater. To form it, the narrower portion may be cut from the cylinder of a moderator lamp and closed at one end by a cork through which one end of a glass tube is passed, the tube having been bent twice, as shown in fig. 134, *A*. The other end of the tube is passed through the cork of the wider vessel, which may be procured by cutting away the

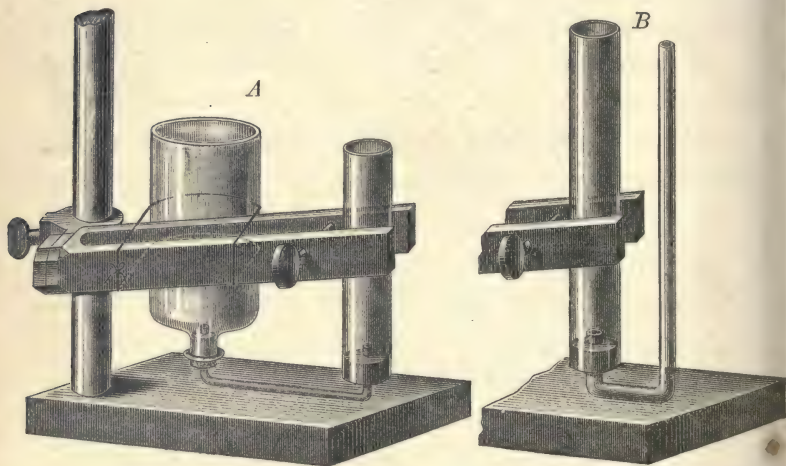


FIG. 134 (*an. proj.* $\frac{1}{4}$ *real size*).

bottom of a common glass bottle. The corks should be firmly fixed in the vessels with sealingwax. The apparatus is rather fragile and not easily placed in a convenient position for use. Fig. 134, *A*, shows a suitable manner of supporting the whole: the horizontal portion of the connecting tube rests upon the foot-board of the retort-stand, the narrower vessel is clamped in the fork, and the wider vessel is tied to the fork with twine. The whole is more easily arranged if it be not required that the heights of the same liquid should be *precisely* equal in both vessels, or those of different liquids *precisely* in the inverse ratio of their specific gravities. In this case the lamp-cylinder may be used as the wider, and a glass tube from 6 to 8^{mm} wide as the narrower vessel, both being connected as shown in fig. 134, *B*. Tubes having an internal width of 1^{cm} cannot be well bent over a common lamp; a narrower one must therefore be used. In such a tube the water will have a

somewhat greater height than that in accordance with the law previously enunciated.

For the experiments with two liquids water is used, with some liquid which does not mix with it, as mercury, ether (the so-called sulphuric ether), olive-oil, or paraffin-oil which is better than any of the others. Mercury (sp. gr. 13.6) and ether (sp. gr. 0.74) differ greatly in their specific gravity from that of water, and do not soil the vessels; but both are rather expensive, and the mercury is not easily poured into the somewhat inconvenient communicating vessels without some of it being lost, while the ether is as colourless as water and not easily distinguished from it at a distance. Olive-oil soils the vessels very much, and as its sp. gr. is 0.9 and more, its height in the vessel is very little greater than that of the water. Paraffin-oil is lighter and leaves the vessels clean after evaporation, especially the lighter kinds sometimes named petroleum-ether, petroleum-naphtha, or what is sold under the name of benzine for removing spots from articles of dress. The specific gravity of these kinds of petroleum varies from 0.8 to 0.7, and even somewhat less.

The heavier liquid is always poured in first. The separation of both liquids after the experiment involves almost always some loss. If water and paraffin-oil have been used, it is best to pour them together into a larger vessel and decant the oil carefully into the bottle, in which it is to be kept, through a funnel. Some of it is, however, always lost.

A body wholly immersed, as in fig. 135, is pressed by the liquid on all sides. It will easily be perceived that the pressures upon the right and left side of the body represented are in equilibrium; this is also the case with the pressures upon the two other vertical sides of the body, viz. that in front and that behind. On the other hand, the pressure upon the lower surface ab is equal to the weight of a column of water represented by $abef$, while the pressure upon the upper surface cd is equal to the weight of the smaller column of liquid $cdef$. The pressure upon the upper surface is there-

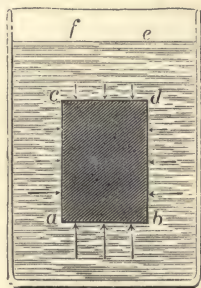


FIG. 135.

fore less than that upon the lower surface by the weight of the liquid column $abcd$. This difference between the pressure on the lower and upper surface of an immersed body constitutes a force which urges the body upwards, and which is called the *buoyancy* of the liquid; the buoyancy is equal to the weight of the volume of the liquid, which is of the same magnitude as the immersed body. This principle, which by reasoning has been established to hold good for a body of regular form, holds equally good for bodies of any form, as may be proved by experiment. The buoyancy being a force acting upwards, in a direction opposite to that in which gravity acts, causes an immersed body to appear lighter than it is: *A body immersed in a liquid loses a part of its weight equal to the weight of the displaced liquid.*

This law is called, after its discoverer, *the Principle of Archimedes*.

At the right-hand extremity of the beam of the balance the short scale-pan is suspended, and to it is fixed, by means of a thin thread, a somewhat large body, for instance, a pebble weighing a few hundred grammes; weights are placed in the scale-pan on the left, until the whole is in equilibrium. The stone is now immersed in water contained in the vessel which was used for the determination of specific gravity (fig. 40, p. 40), and the displaced liquid is received in another vessel. At the moment when the stone dips into the water, the equilibrium of the balance is destroyed, and weights must either be taken away from the left-hand scale-pan, or placed in the right-hand one, in order to restore the equilibrium, as represented

in fig. 136. The weight thus removed from the left-hand scale-pan, or that placed in the right-hand one, represents the weight lost by the immersed body: if

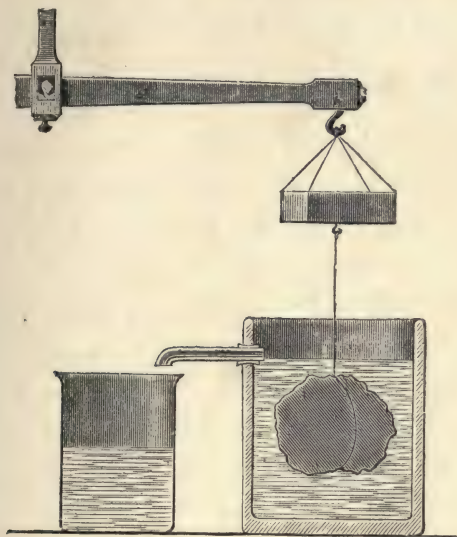


FIG. 136 ($\frac{1}{4}$ real size).

the displaced water be now weighed, its weight will be found to be precisely equal to that loss.

The principle of Archimedes furnishes a method of determining the specific gravity of bodies. For this is obtained by dividing the weight of a body by the weight of a quantity of water occupying the same volume as the body; but the weight of the volume of water displaced by an immersed body is precisely equal to the weight lost by the body, hence the specific gravity of a body may be found by weighing it in air and in water, and dividing its weight in air by the weight which the body loses when immersed in water. In order to find the specific gravity of a body, shot or sand is first placed in

the shorter pan of the balance until it is in equilibrium with the longer; the body is then suspended to the shorter pan by a piece of thread so that it can be immersed in water. Let the body, for instance, be the glass stopper of a bottle; if its weight in air is 46^{gr} , and its weight in water 26^{gr} , its specific gravity is $\frac{46}{46 - 26} = \frac{46}{20} = 2.3$.

The volume of bodies which have an irregular shape may be determined by the same principle. For a body immersed in water loses one gramme of its weight for every cubic centimetre of its volume; hence, conversely, the volume of the body contains as many cubic centimetres as there are grammes in the weight lost by it when it is immersed in water. The glass stopper lost 20 grammes; hence its volume is 20 cubic centimetres.

The loss of weight of a body which floats upon water can only be ascertained by tying to it another body which sinks and causes the first body to be completely immersed. For example, the specific gravity of a piece of cork which weighs 4^{gr} , may be found by tying to it a piece of lead. If the latter weighs 23^{gr} , both together weigh 27^{gr} ; and suppose we find their weight, when together in water, to be 9^{gr} ; if the lead alone weighed in water 21^{gr} , the loss of both together, viz., $27 - 9 = 18^{\text{gr}}$, diminished by the loss of the lead alone, viz. $23 - 21 = 2^{\text{gr}}$, gives the loss of the cork alone, viz. $18 - 2 = 16^{\text{gr}}$. The specific gravity of the cork alone is therefore $\frac{4}{16} = 0.25$.

The specific gravity of a liquid body may be also determined by the principle of Archimedes, for it is only necessary to weigh the same solid body succes-

sively in air, in water, and in the liquid whose specific gravity is to be found. The loss of weight of the body in water gives the weight of a volume of water equal to that of the solid body; the loss in the liquid gives the weight of an equal volume of the liquid; and consequently it is only necessary to divide the second by the first, in order to obtain the specific gravity required. For example, let the glass stopper, which was used before, weigh in air 46^{gr} , in water 26^{gr} , and in alcohol 30^{gr} . This shows that a volume of alcohol equal to that of the stopper weighs $46 - 30 = 16^{\text{gr}}$, while an equal volume of water weighs $46 - 26 = 20^{\text{gr}}$: the specific gravity of the alcohol is therefore $\frac{16}{20} = 0.8$.

The weight lost by a body immersed in a liquid does not disappear altogether. If the body is immersed in a vessel with a lateral spout, as in fig. 136, the displaced water leaves the vessel, and the pressure upon the base is not altered; nevertheless the pressure due to the weight of the displaced water is now exerted upon the base of the vessel into which the water has been discharged. Again, if the water cannot escape, it will rise in the vessel when the body is immersed, and the pressure upon the base of the vessel will increase: the vessel will appear heavier than before, and if it were placed in the scale-pan of a balance and in equilibrium, the increased pressure would cause the scale-pan to descend when a body is immersed in the liquid as shown in fig. 137.

21. *Floating Bodies. Hydrometers.*—When a body which is not much heavier than water (or which has a specific gravity not much greater than unity) is im-

mersed in water, the greater part of its weight is borne by the water, and the body appears very light. Thus very little force is required to keep a man above the surface of water, because the weight of the human body

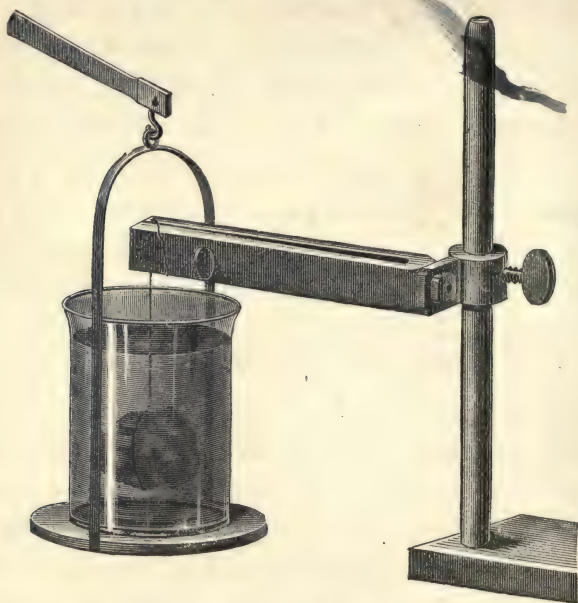


FIG. 137 (*an. proj.* $\frac{1}{5}$ real size).

exceeds only by a few kilogrammes that of an equal volume of water, and a man completely immersed in water loses all his weight except this small excess of a few kilogrammes. If a body had precisely the same specific gravity as the liquid in which it is immersed, it would lose the whole of its weight, that is, the action of gravity which tends to draw the body downwards would in that case be exactly counteracted by the buoyancy of the liquid, which tends to push the body upwards, and the body would be acted on by two equal and opposite forces. Such a body would remain

at rest, wherever it is placed in the interior of the liquid.

A body capable of remaining at rest in every position in the interior of a liquid cannot be maintained in this state for any length of time; for the specific gravity of the body and of the liquid must be exactly equal, but the specific gravity of bodies is constantly altering in consequence of changes of temperature, and these alterations, though slight, are sufficient to cause the body either to sink or to rise in the liquid. A mixture of alcohol and water may be used, as in the case of the drop of oil (fig. 12), for maintaining a solid body suspended within a liquid. If the mixture is not thoroughly stirred, it will contain more water below than near the surface, the lower strata will therefore be heavier, and a piece of stearine-candle will remain at rest when immersed in the liquid. The mixture should contain but little alcohol, for stearic acid, the substance of which these candles are made, is very little lighter than water. If a hen's egg be placed in a saturated solution of common salt in water, it will rise to the surface; but if pure water be gradually added to the solution, the egg may be made to sink below the surface and may be kept suspended in the interior of the liquid.

If the specific gravity of a body is less than that of the liquid in which it is immersed, the volume of liquid displaced weighs more than the body; the 'loss of weight' exceeds in this case the weight itself, that is, the upward pressure of the liquid predominates over the action of gravity on the body, and the latter rises to the surface: the body *floats*. The weight of a floating body is exactly borne by the liquid, and as by the principle of Archimedes an immersed body loses a part of its weight equal to the weight of the displaced liquid, it follows *that the weight of a floating body is equal to the weight of the displaced volume of liquid*. A body which weighs 100^{gr}, displaces 100^{gr} of water when it floats, that is, 100^{cc} of the volume of the body is immersed below the surface of the liquid.

This fact may be demonstrated by means of the vessel with a lateral spout. The vessel is filled with water, and the portion above the spout allowed to run away. A body lighter than water is then weighed, placed in the water in the vessel, and the portion which now runs out by the spout is received in a tumbler and weighed. Its weight will be equal to that of the body.

To obtain an exact result in this experiment, care must be taken lest the floating body touch the sides of the vessel; this often happens if a piece of wood is used; an apple answers very well for the experiment.

If the same body be made to float in different liquids, the volumes of the immersed portions of the body also differ. This may be illustrated as follows: a rather large test-tube is fixed upright in the retort-stand, and as much alcohol is poured into it as will just reach the top when a smaller test-tube is placed almost completely inside it; this smaller tube is then weighted with shot or clean sand until it just floats, in the manner shown in fig. 138 *A*. The larger test-tube is next filled with water in place of alcohol; it will then be found that the small tube sinks to only about four-fifths of the depth to which it sank in alcohol; and if a saturated solution of salt be used instead of water it will sink still less. The reason of this is obvious. The displaced liquid must in each case weigh as much as the floating test-tube. If the weight of the latter is 12^{gr} , the volume immersed in water will be 12^{cc} . But 1^{cc} of alcohol weighs only about $0^{\text{gr}}\cdot8$, while 1^{cc} of the saline solution weighs about $1^{\text{gr}}\cdot2$; hence 12^{gr} of alcohol have a volume of

$\frac{12}{0.8} = 15^{\circ}$, and 12^{gr} of the solution a volume of

$\frac{12}{1.2} = 10^{\circ}$. It follows that in alcohol 15° , and in the

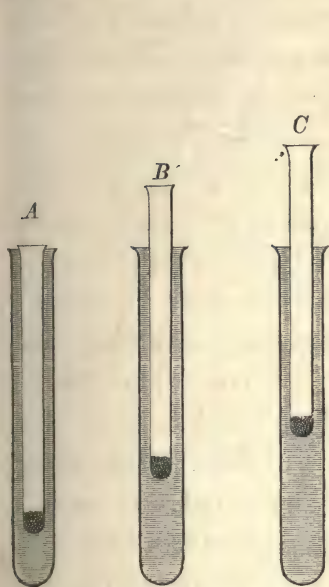


FIG. 138 ($\frac{1}{4}$ real size).

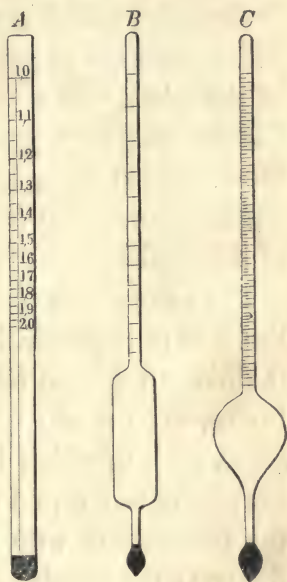


FIG. 139 ($\frac{1}{3}$ real size).

solution 10° will be the volumes displaced by the floating tube. Now $15^{\circ} : 12^{\circ} :: 1 : 0.8$, and $12^{\circ} : 10^{\circ} :: 1.2 : 1$,—hence : *The volumes displaced by the same body when floating in different liquids are inversely proportional to the specific gravities of the liquids.*

This is the principle on which *Hydrometers* are constructed. They are instruments, usually of glass, having one of the forms shown in fig. 139. They are weighted at their lowest part by mercury or shot, which makes them float upright in the liquid. A graduated scale is placed in the interior of the upper part, and that division of the scale which is on a level with the

surface of the liquid in which the hydrometer floats, gives either the specific gravity of the liquid, or its percentage composition if the liquid is a mixture, as, for instance, common spirit of wine, in which case the hydrometer (alcoholometer) usually indicates the relative amounts of pure alcohol and water in 100 parts of the spirit. In other kinds of hydrometers the scale has an arbitrary graduation, and its indications are then referred to special tables, which supply the required information on the specific gravity or 'strength' of the liquid.

For example, *Baumé's hydrometer* sinks in water to the zero of the scale, but in concentrated sulphuric acid it sinks to the division marked 66. The distance between the marks 0 and 66 is divided into 66 equal parts, each of which is called a degree. The specific gravity of any liquid can then be found by means of the instrument with the help of the following rule: Subtract the number of degrees on the scale to which the instrument sinks, from 144, and divide 144 by the difference: the quotient is the specific gravity of the liquid. For example, suppose the instrument has sunk

in a liquid to 20° on the scale; then
$$\frac{144}{144 - 20} = 1.16$$

is the specific gravity of the liquid.

22. *Fountains. Efflux from Orifices. The Screw-Propeller.*—If an open vessel which contains a liquid has an orifice anywhere below the surface of the liquid, the latter will escape through the orifice, in consequence of the action of gravity; if the orifice is not too near the surface, the liquid will be forced out with a certain amount of pressure, and will form a jet. If the orifice

is turned upwards as in fig. 140, the jet will be directed upwards and reach a height which depends on

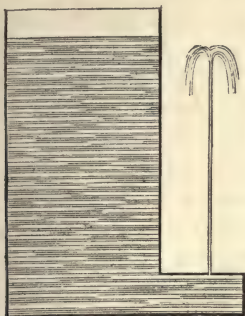


FIG. 140.

the depth of the orifice below the surface of the liquid. The ascending jet would rise to the level of the liquid were it not for the resistance of the atmosphere and the friction of the liquid particles against the sides of the vessel and the edges of the orifice ; these resistances diminish the elevation of the jet considerably, especially when the vessel is not very wide, as in fig. 140, or when part of it is formed by a long narrow tube, as in fig. 141. In ordinary fountains the orifice from which the jet escapes is connected by a series of tubes, often of great length, with a reservoir which is placed at some height above the orifice; the elevation of the jet is in such a fountain considerably less than the height of the reservoir from which it issues, in consequence of the great friction which takes place within the conducting tubes.

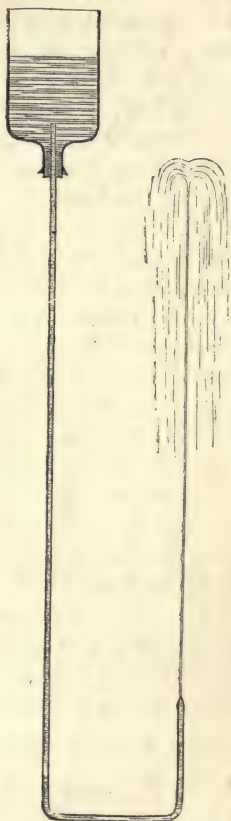


FIG. 141 ($\frac{1}{5}$ real size).

On a small scale a fountain may be constructed in various ways. The bottom of a wine-bottle may be removed by filing a rather deep notch with the three-cornered file, producing a crack with a pastille, and leading it all round; the notch should be filed several centimetres distant from the bottom, for if too near to the latter, the crack cannot easily be led all round. A glass tube from 50 to 80^{cm} long and about 5^{mm} wide, which has previously been drawn out into a fine point and bent twice at right angles, is passed through a perforated cork which is fitted into the neck of the bottle (and if necessary fixed with sealing-wax) as shown in fig. 141. The neck of the bottle should be capable of being fixed in the retort-stand. Instead of a bottle, a glass funnel may be used, which does not require the bottom to be removed. Or the glass tube may be replaced by a long india-rubber tube, one end of which passes over the neck of a funnel, or, if the neck is too wide, over a short glass tube inserted into the neck by means of a cork, while a glass tube drawn out into a point is inserted into the other end. The funnel may be clamped into the retort-stand and the glass tube held in the hand. To increase the elevation of the jet, it should be directed not vertically upwards but somewhat obliquely, for if the jet is vertical, the drops which fall back after having reached the greatest height impede the upward motion of those drops which are still ascending, and thus diminish the elevation of the jet. The fork which holds the vessel with water may be placed near the edge of the table and clamped by means of a hand-vice; the tube descends along the side of the table, and the water is received in a large basin. A better way of constructing a fountain will be explained further on when speaking of the siphon.

In vessels without lateral orifices, as those in figs. 114, 115 and 116, the sides are pressed by the liquid with equal force in every direction; hence the vessel does not tend to move in any direction whatsoever. This equilibrium of the pressure on the sides of a vessel is however destroyed, if an aperture at any point in the side allows the liquid to escape, as in fig. 142, where the aperture is on the right-hand side of the vessel. The area of this side will thus be smaller than the area of the left side by the size of the aperture, and the pressure upon the left side is greater than upon the

right; and if the vessel is easily moveable, the excess of pressure on the left wall would move the vessel towards the left. In a similar manner, whenever liquid is discharged from an aperture, the side opposite to it is pressed in a direction contrary to that of the issuing jet; this pressure may be called *the reaction of efflux*.

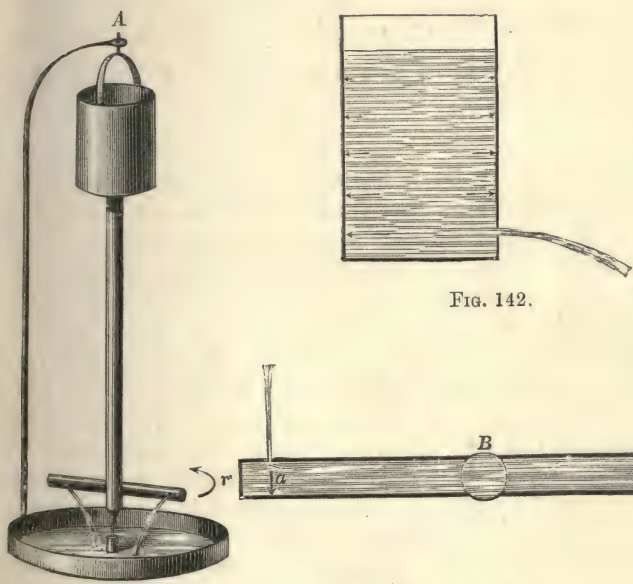


FIG. 142.

FIG. 143 (*A*, an. proj. $\frac{1}{10}$ real size, *B* $\frac{1}{3}$ real size).

Motion may be produced by this reaction by means of an apparatus usually called *Barker's wheel*, the form of which is shown in fig. 143 *A*, while fig. 143 *B* is a section of the lower part. The efflux takes place through the orifices *a* and *b*, and its reaction causes a rotation in the direction of the arrow *r*. The effect of this reaction has been actually employed on a large scale for moving machinery by means of water; such

contrivances have, however, usually a form which differs from that shown in the figure, although the principle is the same; the principal difference consists in this, that in the apparatus shown in the figure, the water is conveyed to the horizontal cylinder from above, while the larger machines are so arranged that the water enters the wheel from below, by means of a tube which is connected water-tight with the horizontal cylinder without impeding its motion. Small wheels of a similar kind are often used as ornamental additions to fountains.

A reaction-wheel can be easily made as follows: a metal ring, across which a strip of sheet brass is soldered, with a hole 2 or 3^{mm} wide, drilled or punched through it exactly at the centre, is fixed with sealing-wax round the wider end of a lamp-cylinder. The other end of the cylinder is fitted with a long cork, through which three holes are bored lengthwise—one at the middle, to admit a piece of stout steel wire filed to a blunt point at one end, and two near opposite sides, to admit glass tubes. The piece of steel wire should be 25^{mm} longer than the cork, so that it may be put quite through the cork and still project 2^{cm} below the cylinder when the cork is pushed 5^{mm} into the cylinder. It must be fixed very firmly in the cork; a hole is therefore made in the cork with the bradawl, but is not widened, care being taken that it is bored quite straight, so as not to give a slanting direction to the point. A glass tube, 25 to 30^{cm} long and 4^{mm} wide, is drawn out in the middle until the width of the thinnest portion is reduced to 1^{mm}.5; a scratch is made at that point and the tube broken in two. The points thus produced should not be fine and long, but rather short; to obtain such points, the tube must be continually turned in the flame and drawn out at once; if the tube is allowed to become soft before it is drawn out, the points become too long and fine for our purpose. Both tubes are twice bent at right angles, 2 or 3^{cm} from each end, but so that the pointed end may be horizontal when the other end is vertical. The holes for the tubes are bored through the cork on opposite sides of the steel wire and at equal distances from it. The whole being put together in the manner shown in fig. 144, the cork is fixed with sealing-wax, with the help of the blow-

pipe; during this operation the side of the cork which is turned downwards in the figure must evidently be turned upwards, and the sealing-wax must be allowed to cool before the apparatus is set to work. For this purpose a hollow is made with the centre-punch in a small piece of sheet-metal for the reception of the steel point; two holes are also drilled through it, so that it may be fixed by two screws to the foot of the retort-stand. Finally, a piece of wire of such thickness that it may easily turn in the hole of the brass strip at the top of the cylinder is bent at right angles and clamped as shown in the figure; the portion of the wire which is bent downwards should be slightly oiled, a drop of oil should also be placed in the hollow made for the pivot. The whole is best placed in a small tub, to prevent the splashing about of the water. The cylinder may be filled with water from a jug with a spout, and kept nearly full for some time. It will immediately begin to rotate, and if it be provided with four orifices instead of two the motion will be still more rapid.



FIG. 144 (*an. proj.* $\frac{1}{6}$ real size).

A wheel, formed of several pieces (4 or 6), which are placed in an oblique direction upon the axis, as shown in fig. 145, may be considered as a portion of a screw, which has as many threads as there are pieces or 'blades.' If such a wheel is made to rotate in water, it will also move forwards in the water, because the water, which acts the part of the nut in this case, tends to remain at rest by its inertia; thus, if the wheel were turned in the direction of the arrow *d*, it would at the same time have a progressive motion in the direction of the arrow *f*. Wheels constructed on this principle are briefly called *screws*, and, as is well known, are used for propelling steamships.

Conversely, if a screw of this kind is fixed in such a manner that it may rotate but cannot move forward, it will rotate if the water moves in the direction of the axis of the screw ; thus, if the water flows in the direction opposite to that of the arrow f , the screw will rotate in the direction of the arrow d .

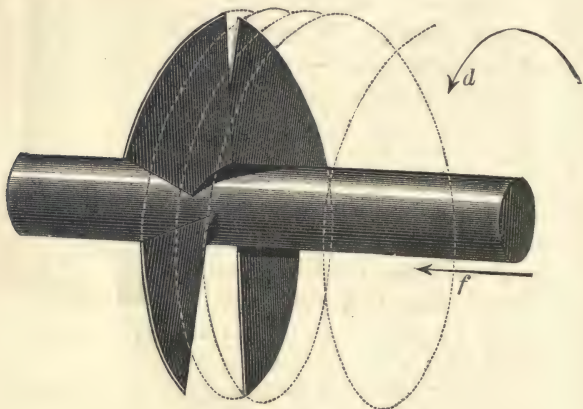


FIG. 145 (*an. proj.*).

The glass cylinder of a lamp is provided with a ring, with a perforated strip across it, as for the experiment on the reaction of efflux ; the ring, however, is not fixed with sealing-wax, but put on loose so that it may be removed and put on again at will. Another thin strip of metal, preferably of sheet brass, is cut 4^{cm} long and 5^{mm} broad, a cavity is made in the middle with the centre-punch, and the ends of the strip are bent, so that it may be pushed with moderate friction into the inside of the cylinder. The strip is fixed at about the middle of the cylinder by placing a piece of sealing-wax about the size of a pea at one end of the strip close to the glass and heating the latter cautiously from outside until the wax melts ; the liquid wax will flow of itself into the space between the metal and the glass. When one end is thus fixed and has become cool, another small piece of wax is used in the same manner to fix the opposite end of the strip. The lower end of the cylinder is closed by a cork which has a hole about 8 or 10^{mm} wide in the middle. The spindle of the screw is formed of a straight piece of steel wire 3^{mm} thick, and somewhat longer than half the length of

the cylinder, one end of which is filed to a blunt point. A circular disc of thin brass is now prepared, having a diameter which is 1mm less than the internal width of the glass cylinder at *a*, fig. 146 *A*, and a hole is drilled in the middle, into which the steel wire fits rather tight; the hole should therefore be made at first too narrow, and then cautiously widened with the rimer. The disc should be soldered to the wire so as to be at *a* in the cylinder when the point of the wire rests in the cavity of strip *b*. From six points of the

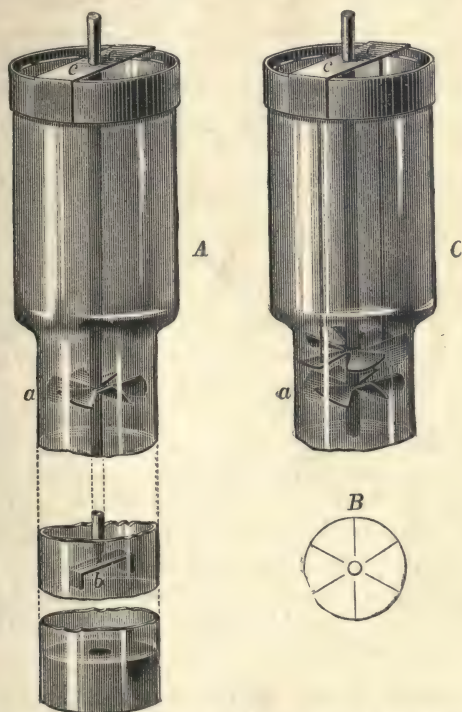


FIG. 146 (*A* and *C*, an. proj. $\frac{1}{2}$ real size; *B* $\frac{1}{2}$ real size).

edge equally distant from one another, cuts are made with the shears to about $1\text{mm}\cdot5$ from the spindle, as shown in fig. 146 *B*; six blades are thus formed, which are bent with the flat pliers into the oblique positions shown at 146 *A*. The hole *cc* in the cross-strip at the top should be widened with the rimer so as to allow the spindle just to pass easily through it, but not too loosely. The screw is placed within the cylinder, and the ring with the cross-strip upon the top of it; the whole is clasped in some convenient way, the hole in the cork is closed with the

thumb of the left hand, and water poured with the right hand into the cylinder. When the finger is withdrawn, and the water is allowed to flow through the aperture into a vessel which has been placed ready for its reception, the screw will rotate, and the rotation may be maintained for some time if the cylinder is kept full by constantly pouring in water at the top.

This apparatus becomes a good approximate model of a *Henschel's Turbine*—a kind of water-wheel recently much used on a large scale for imparting motion to machinery—if another wheel is placed in a fixed position above the moveable one, but having the blades inclined in a direction opposite to that of the blades of the moveable wheel. The fixed wheel may be made of a circular disc of metal, so large as just to fit into the narrower part of the cylinder, and having a hole in the middle which must be at least 1^{mm} wider than the thickness of the spindle. In cutting the blades these will slightly bend by the pressure of the shears, but as their inclination is the same as in the moveable wheel, the blades must first be all straightened with the wooden mallet, and then bent in the other direction with the flat pliers; if this is done without previously hammering the disc flat, the latter is likely to be spoiled. Two brass wires, about 1^{mm} thick, are soldered with one end to two opposite blades of the screw, with the other to the cross-strip at the top; the wires should have a length which permits the two screws to be as near as possible to one another without touching. Fig. 146 *C* shows the upper portion of the whole apparatus. By using two moveable screws, one without and the other with a fixed screw, it will at once be observed that the latter increases the velocity of rotation considerably: the blades of the fixed screw direct the current of water in such a manner as to produce a much greater effect upon the moveable blades than the current would have upon them if it were simply to flow in a vertical direction.

When a liquid flows rather rapidly through a tube, which becomes suddenly wider at one part, certain phenomena may be observed which will be considered after the effects of atmospheric pressure have been studied.

23. *Molecular Phenomena. Adhesion. Capillarity. Solubility. Diffusion. Endosmose.*—Some of the phenomena which depend on the action of molecular forces upon liquids, especially the tension of liquid surfaces, have been already studied in articles 3 and 4.

As a consequence of their mobility, liquids manifest strongly the force of *adhesion*, for they come into close contact with solids, whatever the form of the latter bodies. A hand dipped into water and withdrawn, is covered with adhering drops. A drop of water placed between two adhesion-plates causes them to adhere much more firmly. The degree of adhesion between a solid and a liquid body cannot, however, be immediately deduced from the more or less moistened state of a solid which has been immersed in a liquid, for the state of the surface of the body is of considerable influence; thus water will adhere only in a slight degree to a body which has a greasy or dusty surface.

If *lycopodium* (the fine powdery seed of several species of the *Lycopodium*) be scattered over a board or a table, by means of a wide-necked bottle with a piece of muslin gauze tied over the mouth, drops of water which are let fall upon the surface so covered will not spread out upon it, as is usually the case, but will roll along the surface in the form of globules. If the surface of the water in a basin be covered with a layer (not too thin) of the same powder, the hand may be immersed to some depth into the water without being wet. It would, however, be incorrect to conclude from these facts that there is no adhesion between the water and the fine resinous granules of the *lycopodium*; the powder in these experiments merely hinders the contact between the water and the table or hand respectively, and thus prevents the manifestation of adhesion; if the globules of water are examined, they will be found covered with the powder.

There are, however, cases in which no adhesion is

manifested between a solid and a liquid. A finger, a glass-tube, a piece of sealing-wax, or a pencil immersed in mercury and withdrawn, will show no trace of the liquid upon their surface ; nor will adhesion be manifested if mercury be thrown upon a clean table ; globules will be formed in the same manner as when water is thrown upon a table covered with lycopodium. The metals alone, among common substances, are wetted by mercury, though even among them iron is an exception, and the rest are wetted only when their surfaces are perfectly clean. Nevertheless it may be shown that adhesion exists even if the solid surface is not moistened by a liquid. A small square or round plate of glass is suspended by the hook attached to the short scale-pan of the balance and counterpoised. A vessel containing some mercury is placed underneath the glass plate so that the latter may just touch the surface of the mercury, as shown in fig. 147 ; the plate will adhere to the liquid, and weights amounting to several grammes will have to be placed in the other scale-pan to detach the plate again. If water be used instead of mercury, only about a third of the weights used in the experiment with mercury will be needed to effect the separation of the plate from the liquid ; but it would be erroneous to conclude from this that the adhesion between glass and mercury is three times as great as that between glass and water, for the weights used in the latter experiment have in fact not overcome the adhesion between glass and water ; the glass plate is covered with drops of water, and the force represented by the weights has been chiefly used for detaching some of the liquid from the remaining mass. The experiment proves no more than

that the adhesion between glass and water is greater than the mutual attraction of the particles of water, and generally: *A solid body is moistened by a liquid if the cohesion of the liquid is less than the adhesion between it and the solid ; but if the cohesion is greater than the adhesion, the solid will not be moistened by the liquid.*

The glass plate should have a size of 2 or 3^{cm}, and you may either cut it circular with pastille, or have it cut square by a glazier.

The mercury used in this and in many other experiments must be free from impurities, for only pure mercury retains its bright surface permanently ; impure mercury becomes tarnished on the surface, has a dull appearance, and sticks to glass and other bodies, covering them with a grey layer. Mechanical admixtures, such as dust, are easily got rid of by pouring the mercury through a funnel made of a piece of blotting paper, which is twisted into the shape of a cone, with a fine aperture at the point ; the impurities remain behind, and adhere to the paper. The last portion of the mercury in the funnel will not run easily through the fine aperture ; it should be dropped separately into a small vessel, and kept for some experiments which, as will be seen farther on, do not require mercury in a perfectly pure state. Mercury which has become moist by water may be dried by blotting paper ; the larger drops of water are as far as possible sucked up by strips of paper, and the remainder is filtered through a cone of blotting paper. From the property which mercury possesses of dissolving most metals, it often contains impurities which are more difficult to deal with than those previously mentioned. Mercury which is rendered impure by the presence of other metals leaves a considerable residue on the paper filter, and exhibits for a short time after filtration the bright lustre of the pure metal ; but it becomes soon covered with a grey film, and if the quantity of foreign substances is considerable, it loses its mobility and the surface becomes covered, even immediately after filtering, with numerous thin folds and ruffles. The purification of such mercury is

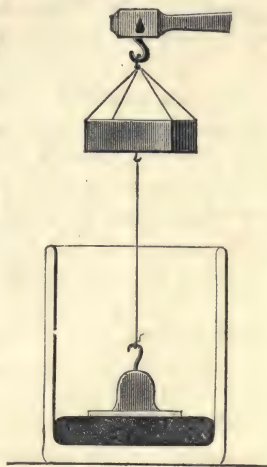


FIG. 147 ($\frac{1}{2}$ real size).

a difficult operation, and it is therefore best to purchase the mercury of the purest quality, and carefully to avoid bringing it in contact with other metals, such as zinc, lead, etc., but especially with gold and silver, for in the latter case not only the mercury, but also the gold and silver will be spoiled; valuable articles of gold and silver should hence be put away while mercury is being handled. Mercury is poisonous, although not in such a degree as is usually believed, and much less so than some of its chemical compounds, which are among the most poisonous substances known. Caution is therefore necessary in handling mercury, that none of it be taken into the mouth or swallowed; to touch mercury with the hand is harmless, but even this should not be done without some definite purpose, for the mercury becomes impure by the oily and watery exhalations of the skin. Mercury must not be heated, for it combines in that case with oxygen, one of the constituents of our atmosphere, and is thereby not only rendered useless for physical purposes, but becomes also much more poisonous.

Mercury is somewhat expensive, but one kilogramme is absolutely necessary for our purposes; 1^{kg} measures only 73^{cc}·5, for 1^{cc} weighs 13^{gr}·6, and it is certainly much better to be able to purchase a larger quantity. In any case care is necessary not to lose any of it, for its mobility and great weight render it rather difficult to handle mercury without losing some of it. If mercury falls from a height, such as that of a table, upon the floor, it becomes separated into globules so minute, that generally only a very small portion can be recovered. It is therefore advisable to make all experiments in which mercury is employed upon a tray, consisting of a flat board, surrounded on all sides by a rim about 3 or 4^{cm} high. If the joints between the rim and the board are not perfectly tight, or become somewhat detached in course of time by the drying of the wood, the chinks should be filled up with putty, or paper should be glued over them. Instead of a tray of wood, one of stout pasteboard may be used; to render it strong enough the joints at the corners must be glued over with paper inside, and with bands of linen outside; the glue used for the linen should be rather thick.

The free surface of a liquid is a horizontal plane, but where the liquid is in contact with the sides of the vessel or any other solid body, the surface of the liquid becomes curved, and the form of the curve differs according as the solid is or is not moistened by the

liquid. If the solid body is moistened by the liquid, the surface becomes curved upwards against the sides of the solid—it is *concave*; if, on the contrary, the solid is not moistened by the liquid, the liquid is depressed against the sides of the solid—the surface becomes *convex*.

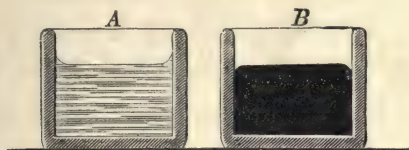


FIG. 148 (*real size*).

Fig. 148 *A* represents the surface of water in a vessel of glass. Fig. 148 *B* represents the surface of mercury in a vessel of glass. In tubes of which the internal diameter is less than 1 cm , the whole surface of the liquid becomes curved; if such a tube is placed in a liquid which wets it, the surface of the liquid in the tube will be above the surface of the liquid outside. The ascent of liquids in tubes is especially well marked if the bore is very narrow, not larger than a hair (*Lat. capillus*); such tubes are called *capillary* tubes, and the phenomena themselves are investigated under the name *capillarity*. If a tube is not moistened by the liquid in which it is placed, the surface of the liquid within the tube will be below that of the liquid outside. It is impossible to enter here upon an explanation of these phenomena by the action of molecular forces; it will be sufficient to describe some experiments on capillary phenomena.

If several tubes of different internal diameters be placed side by side in a liquid which wets them, as shown in fig. 149, it will be seen that the liquid stands higher when the tube is narrower, and that the

liquid will stand twice as high in a tube which has half the width of another ; if a tube has one-third the internal diameter of another tube, the liquid will rise in it to a height three times as great as in the wider tube : *The height of ascent in capillary tubes is inversely proportional to the internal diameter of the tubes.*

If a capillary tube is placed in mercury, the surface of the liquid in the tube is depressed below the surface of the external liquid ; but mercury being not transparent

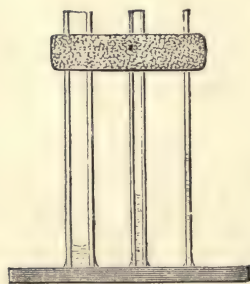


FIG. 149 (*real size*).



FIG. 150 (*real size*).

like water, it is somewhat difficult to observe the depression. In order to prove the fact that mercury is depressed in a capillary tube, it is most convenient to use two communicating tubes, like those in fig. 150, one of which has a very small diameter.

A liquid placed between two solid walls, which are moistened by it, will rise the higher the narrower the space between the walls. This may be shown by means of two rectangular plates of glass, placed in a liquid, so that their edges on one side may be in contact, and on

the other separated by a few millimetres, as shown in a horizontal section in fig. 151 *B*. The liquid will rise between the plates in such a manner that it will be highest on that side where the plates are nearest together, and the upper surface of the elevated portion of the fluid will form a peculiar curve, as shown in fig. 151 *A*, which gives a side view of the plates with the liquid between them.

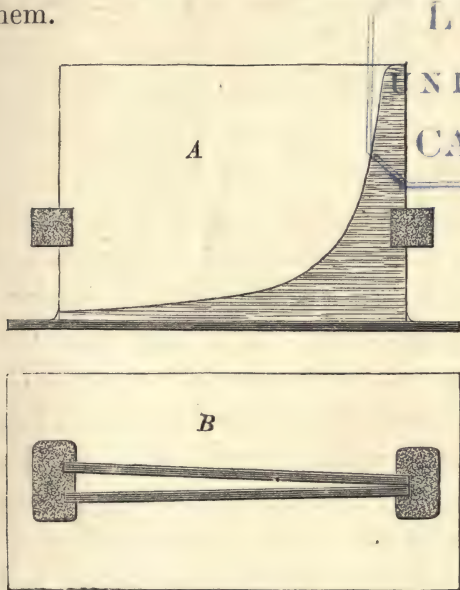


FIG. 151 (*real size*).

For these experiments alcohol should be used in preference to water. For dust cannot be prevented from getting inside the tubes, and it will interfere with the moistening of them more if water is used than if alcohol is employed. Tubes of 2^{mm} diameter may easily be bought; alcohol will ascend in such a tube to the height of a few millimetres. Narrower tubes may be prepared over the spirit-lamp. A glass tube about 8 or 10^{cm} long, and 4 or 6^{mm} wide, is heated in the middle, constantly turning it until it has become quite soft; it is then taken at once away from the flame and rapidly drawn out. In this manner a very narrow tube of from 20 to 60^{cm} is obtained, from which suitable pieces may be cut with the three-cornered file. A piece of 6 or 8^{cm} may be left at one end of

the tube, and bent into the form shown in fig. 150 ; the fine narrow tube, however, must not be bent in the flame, but above it, otherwise it will form a sharp bend. The mercury is poured into the wider end of the tube by means of a small paper funnel.

The glass plates should be cut by a glazier out of a very flat piece ; they should be from 4 to 6^{cm} long and 3 or 4^{cm} wide. They are clamped between two pieces of cork of a suitable form, shown in fig. 151 *B*, and placed in a very shallow saucer or upon a flat piece of glass, which may also serve for the experiment with the tubes (fig. 149) ; it is then only necessary to place a few drops of alcohol upon the plate, with a pipette or a glass rod.

The ascent of liquids in bodies which possess fine pores or cavities is also caused by capillarity ; it is from this cause that water rises in wood, sponge, sugar, blotting-paper, or oil in the wick of a lamp. Bodies float on the surface of a liquid because, as we have seen, the upward pressure of the liquid is greater than their weight. It follows that if a body can be placed upon the bottom of a vessel in such a manner that there is no liquid between it and the vessel, no upward pressure can be exerted upon it, and the body will not rise to the surface. Thus a flat cork, having one side very evenly cut or filed, and placed with that side upon the bottom of a small vessel or saucer, will not rise if mercury be poured over it, provided that the cork be prevented from sliding while the mercury is poured into the vessel by a slight pressure of the finger ; if the finger is removed, it will even require a certain amount of force to lift the cork from the bottom in consequence of the downward pressure of the liquid. This experiment will not succeed with water, because the action of capillarity forces some water between the cork and the bottom of the vessel, even if their contact is very close ; but if care be taken to prevent the liquid from moisten-

ing the bottom of the vessel and the lower surface of the cork, the experiment may be made in water with the same success as in mercury.

Melt a small piece of stearine candle in a ladle, and drop some of it upon an adhesion-plate placed horizontally, so as to form a circle of not more than 15^{mm} diameter. Before the molten stearine hardens, place upon it a round piece of cork, about 10^{mm} in diameter, and from 5 to 10^{mm} high. After cooling, the cork with the attached stearine is carefully detached from the plate by gentle pressure from the side. The stearine gives to the cork a surface which is not moistened by water, and the cork is required because the stearine by itself is very little lighter than water; both together form a body which floats. Remove the sealing-wax handle from the adhesion plate, and place the plate upon the bottom of a capacious tumbler, in order to have as even a surface as possible; sprinkle some lycopodium over the plate, place the float of stearine and cork with the flat side upon it, and fill the tumbler cautiously with water, while the float is pressed very slightly to the plate by means of a small rod. When the tumbler is full withdraw the rod; the float, pressed downwards by the liquid, remains at the bottom; but if slightly displaced so that water may get underneath it, the float rises immediately.

Many solid substances are *dissolved* by certain liquids, that is, they become themselves liquid if brought into contact with them: sugar, common salt, gum arabic, are thus dissolved by water, resinous bodies are dissolved by alcohol, etc. The fact of the solubility of a solid in a liquid is explained thus: the adhesion between a solid and a liquid may be either less or greater than the cohesion of the molecules of a liquid; in the case of mercury and glass, the cohesion of the mercury is greater than the adhesion between mercury and glass; in the case of water and glass, the cohesion of the liquid is less than the adhesion between the liquid and the solid. Now, it may happen that the adhesion between a solid and a liquid is also greater than the cohesion of the

solid molecules: in that case the molecules of the solid, if the latter is placed in contact with the liquid, will obey the preponderant force, their cohesion will be overcome by adhesion, and they will be dispersed among the molecules of the liquid. The solubility of solids in liquids is extremely variable: water dissolves sugar to a considerable amount, until the solution becomes a thick liquid like syrup; of common salt about one part may be dissolved in three parts of water. Many other bodies are very soluble; of others, again, only small quantities are dissolved; of gypsum only one part is soluble in 400 parts of water.

Most bodies are more soluble in hot water than in cold, but this rule is not without exception: of common salt and gypsum nearly equal quantities are dissolved whether the water is hot or cold.

Many substances, if their solution is evaporated, or when a saturated hot solution is allowed to cool, are separated again from the liquid as '*crystals*,' that is, the molecules arrange themselves so as to form bodies having regular geometrical outlines bounded by plane surfaces, and being mostly transparent. Common *salt-petre* (potassic nitrate, usually called *nitre*) is soluble in less than four times its weight of cold water, and in less than half its weight of hot water. 100 or 200^{gr} of nitre may be covered with an equal weight of water, and the whole heated until all the nitre is dissolved. The solution is allowed to cool slowly, without being stirred or shaken; beautiful crystals in the shape of six-sided columnar prisms will then crystallise from it.

The solution should be heated in a small china saucer, of the kind usually used in chemical laboratories, and called an 'evaporating

dish.' Any capacious glass vessel, not too high, will also answer the purpose, if care be taken not to heat it suddenly and thus to break it; this may be prevented by placing the vessel into a larger one about 6^{cm} wide, filling the latter a few centimetres high with water, and heating the whole on the hob or on a stove until the nitre is dissolved. That the cooling may not be delayed too long, the vessel containing the solution should be removed from the larger vessel and placed in a quiet spot, for example, a window sill; one or two hours afterwards the liquid portion is poured away, and the interior of the vessel will be found lined with crystals.

Another salt which crystallises readily from hot solutions is *alum*. The relative quantities of alum and water for producing crystals may be the same as in the case of saltpetre, but the form of the crystals is different in the two cases: fig. 152 *A*, represents a single perfectly formed crystal of alum; fig. 152 *B*, one of saltpetre. Such crystals, however, perfectly developed in all directions, are only obtained with difficulty.

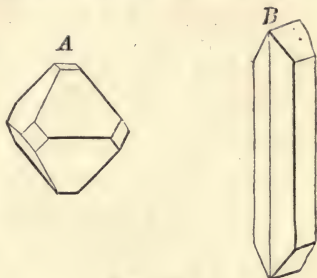


FIG. 152.

Liquids which mix when shaken together, as water and alcohol, water and vinegar, or water and saline solutions, will also mix gradually when simply brought into contact, without being stirred or shaken. This mutual interchange which takes place between the molecules of two different liquids in contact, without the application of any external force, is called *diffusion*. Diffusion proceeds at various rates, according as it is favoured or retarded by the difference in the specific gravities of the two liquids. Two test-tubes, each being large enough to contain about 30^{cc} of water, are filled with water. Into one of the test-tubes about 3^{gr} of 'blue vitriol' (cupric sulphate) are thrown; this substance forms in the solid state beautiful blue crystals, and, when dissolved in water, a blue solution

which is heavier than pure water and becomes heavier the stronger it is. An equal quantity of the blue crystals is placed in a little bag of muslin (or any other thin fabric), and suspended in the water contained in the second test-tube by means of a thread tied to the bag and fixed to a small piece of wood which is placed across the top of the test-tube, so that the bag may be just immersed in the water. In both test-tubes the crystals at once begin to be dissolved. From the suspended crystals, the solution, being heavier than the water, descends to the bottom of the tube, while a fresh quantity of pure water takes its place, dissolves a portion of the solid crystals, becomes heavier and sinks, giving in its turn room for a lighter portion of the fluid, and so on: the greater specific gravity of the solution produces currents which do not cease until the contents of the bag are completely dissolved, and the liquid is coloured uniformly blue. In the other test-tube, solution also begins immediately, but in consequence of its greater specific gravity the blue liquid remains at the bottom of the tube covering the undissolved portion of the crystals; the liquid gradually becomes deep blue and completely saturated, while the upper portions of the liquid remain for a considerable time pure water; only very slowly and gradually, in the course of days and even weeks, diffusion takes place, and months must elapse before the liquid is uniformly blue and the cupric salt is diffused equally through the whole.

It is a remarkable fact that when walls of certain substances, such as gypsum, unglazed and slightly burnt clay, parchment-paper, animal membranes, etc.,

which permit the passage of liquids through them, are interposed between two liquids, they present less hindrance to their mixture than difference in the specific gravities. When two liquids are separated by such a wall, the peculiar phenomenon is observed that the liquids pass through the partition at unequal rates, and that consequently the quantity of liquid on one side of the wall increases, while that on the other side becomes less. In general the heavier liquid passes through the wall at a slower rate than the lighter, but this rule by no means holds good in all cases. This phenomenon is called *endosmose*.

Remove the bottom of a small glass bottle, of about 30^{cc} capacity, by making a cut with the file about 1^{cm}.5 from the bottom, and carrying a crack all round with a pastille. Grind the lower end of the bottle smooth, on the grindstone, or with emery powder on a glass plate, and take off the sharp outer edge of the rim by holding the bottle slantingly upon the stone or plate, and turning it slowly all round; a grindstone will serve for this operation better than emery powder. A piece of calf's or pig's bladder, softened by soaking it in moderately warm water, is stretched very tight across the ground edge, tied very firmly by a piece of thin twine which is wound in close turns six or eight times round the glass, and the protruding points of the bladder are then cut away with a pair of sharp scissors. A soft sound cork is fitted very tightly into the neck of the bottle; the cork is perforated for the reception of a glass tube, as shown in fig. 153. The tube is open at both ends, about 3^{cm} wide, from 10 to 20^{cm} long.

The cork being removed, the bottle is filled with a solution of 20^{gr} of sugar in 20^{cc} of water, again closed, and the projecting glass-tube is clamped in the fork of the retort-stand, the bottle being allowed to dip into a larger vessel containing water, precisely in the manner shown in fig. 153. When the cork is inserted, some of the liquid in the bottle is pressed into the tube, and a small quantity may even run out at the open end of it;

but in a very short time the pressure of the liquid upon the bladder causes the latter to bulge out, the capacity of

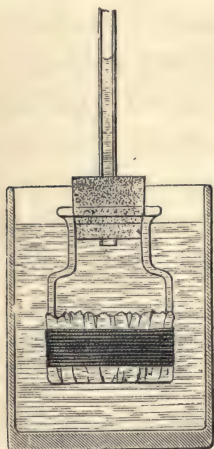


FIG. 153 ($\frac{1}{2}$ real size).

the bottle is thereby increased, and the liquid in the glass-tube recedes again into the bottle. Very soon the extension of the bladder by pressure, and the consequent descent of the liquid in the tube, reach a limit; the liquid is now seen to rise slowly in the tube, because the water in the outer vessel passes more rapidly through the bladder to the solution of sugar, than the latter passes from the inner vessel to the water. In the course of a few hours the liquid rises several centimetres, and if a narrower tube be used, the liquid will clearly rise still higher.

Water and white of egg manifest strong endosmose. The pellicle which lines the shell and surrounds the liquid contents of the egg, may be used with advantage for exhibiting the phenomenon. About 40^{cc} of crude concentrated hydrochloric acid are mixed with about 200^{cc} of water in a capacious vessel, capable of containing about a litre. When a hen's egg (one with a thin shell being selected) is placed in the liquid, the shell is dissolved with strong effervescence; after about half an hour, the liquid having been frequently but very cautiously stirred with a splinter of wood, the whole of the hard shell is removed. The whole of the liquid and froth are now carefully poured off; the egg, which has become pellucid and quite soft, is repeatedly washed with clean water, and the vessel also

thoroughly rinsed. The egg is then placed in water, which is renewed every day two or three times. At first the water, after the egg has remained in it for some time, has a distinct acid taste until the acid which has penetrated into the egg has passed out again; but the white of egg will not pass through the pellicle, while a great quantity of water will gradually penetrate the membrane; within two days the egg, which had originally a weight of scarcely 50^{gr}, will swell considerably and attain a weight of about 80^{gr}.

3. *Aërostatics and Aërodynamics, or, the Equilibrium and Motion of Gaseous Bodies.*

24. *Weight of Air. Loss of Weight in Air. The Balloon.*—It has been shown in art. 2, that air possesses the general properties which are common to all bodies. Air is, like all other bodies, acted on by gravity, and hence it has weight. But the weight of air is very small: the specific gravity of atmospheric air under ordinary circumstances is about $\frac{1}{800}$; of the other gases some are rather heavier, some are even lighter than air.

If a pig's bladder is weighed in a compressed state—that is, when empty—and again when distended by having air blown into it, the weight of the bladder will be found the same in both cases. But it would be an error to conclude from this that air has no weight; for the same result would be obtained by weighing the bladder, while immersed in a vessel of water, first in the compressed state and afterwards filled with water.

If the bladder contains 1,000^{gr} of water, its weight increases by 1,000^{gr}, but at the same time its volume increases also by 1,000^{cc}, and the loss of weight in water amounts, in consequence of the greater volume, exactly to 1,000^{gr} more than before; hence the bladder appears equally heavy in both cases. Gases transmit pressure and exert pressure upon the bottom of vessels in the same manner as liquids, and the principle of Archimedes, which is a consequence of fluid pressure, must therefore also be applicable to gases. Accordingly a body in air loses a part of its weight equal to the weight of the displaced air. When the bladder is filled with air, its weight and its volume are increased at the same time; but the bladder now displaces more air than before, and consequently loses an additional part of its weight, and this loss is exactly equal to the increase in the absolute weight; hence the apparent weight remains the same.

To show the weight of air, a vessel with rigid walls, and hence not capable of altering its volume, must be weighed empty, and again when filled with air. A glass flask with thin walls, of about 1 litre capacity, that is, having, at least, a diameter of 13^{cm} at the widest part, is provided with a well-fitting cork, glass-tube, india-rubber tube, and pinch-cock, and the air is expelled from it in the manner explained in art. 4 (page 18). The bottle is then suspended by a thread, tied round its neck, to the short scale-pan of the balance which was used in the hydrostatic experiments, and exactly counterpoised by weights in the other scale-pan. The pinch-cock is now opened, the air is heard to enter the flask with a distinct sound, and the

scale-pan with the flask descends; 1^{gr} or more will have to be placed in the other scale-pan to produce equilibrium: that is, the air which enters the flask weighs one gramme or more.

The loss of weight which bodies undergo in air is generally very small in comparison with the weight of the bodies; hence the loss is practically disregarded in the transactions of common life. But if bodies really lose part of their weight when surrounded by air, it follows that bodies will float in it if their weight is less than that of an equal volume of air. Some gases are indeed lighter than air, for example common coal-gas, which is about half as heavy as air; and there is a gas, hydrogen, which is the lightest of all known bodies, and weighs less than one-fourteenth of the weight of air. Both these gases consequently float on air, that is, they rise in it. This may be shown by holding a stout test-tube, or a lamp-cylinder which is closed at one end by a tight cork fixed with sealing-wax, over a common gas-burner, so that the nozzle of the burner is well within the tube. The cock being opened, allow the gas to issue from the burner while you are counting twenty, that is, for about twenty seconds. Close the cock, hold the tube or cylinder in the same position for another twenty seconds, and now hold a lighted lucifer-match to the open end. The coal-gas having ascended in the tube in virtue of its being lighter than air, which it has pushed downwards and out of the tube, fills the latter completely, remains in it for some time afterwards, and manifests its presence by burning when the lighted match is applied to it. If the experiment is repeated with this alteration, that immediately

after the cock is closed the tube is inverted and kept for twenty seconds mouth upwards, the lighted match will not inflame the gas in the tube, for the coal-gas has now escaped upwards, out of the tube, and the latter is filled by the heavier air.

If the experiment be performed precisely in the manner described, it will always succeed; but a bottle should never be used for it. The air or the gas cannot within twenty seconds escape so rapidly through the narrow neck of a bottle as not to leave some of it in the bottle; a mixture of both is therefore obtained which does not burn quietly, but explodes with greater or less vehemence according to the proportion in which the two gases are mixed. If the mixture should accidentally contain air and gas in a proportion very favourable to an explosion, the latter will be very violent and loud, and the bottle may be shattered into fragments, which will be thrown in all directions and may cause serious accidents. A vessel which has an equal width throughout, or becomes only somewhat wider at the mouth, such as a test-tube or a lamp cylinder, will not be broken even if, in consequence of an insufficient supply or discharge of gas, an explosive mixture should have remained behind.

Soap-bubbles filled with coal-gas or hydrogen rise rapidly in the air, because the thin liquid envelope together with the gas is still lighter than the air which they displace. A *balloon* is nothing else but a capacious envelope filled with gas, forming together a body lighter than an equal volume of air. A spherical balloon of 12^m or 120^{dec}m diameter has by the rule given in art. 1 (page 6) a volume of $\frac{120 \times 120 \times 120 \times 3.1416}{6}$

= 904,780.8 litres. A globe of water of this volume would weigh an equal number of kilogrammes, for 1 litre of water weighs 1^{kg}; but the weight of air is $\frac{1}{800}$ of that of water, hence a volume of air equal to that of the balloon weighs only $\frac{1}{800} \times 904,780^{\text{kg}} \cdot 8$, that is, nearly 1,131^{kg}. When the balloon is filled with coal-

gas, which has half the weight of air, its contents will weigh $\frac{1131}{2} = 565^{\text{mgr}}\cdot 5$, and hence the balloon will rise if the envelope with all appendages weighs less than $565^{\text{mgr}}\cdot 5$. If the envelope weighs 300^{mgr} , the weight of the balloon is $565\cdot 5 + 300 = 865^{\text{mgr}}\cdot 5$, which is $1,131 - 865\cdot 5 = 265^{\text{mgr}}\cdot 5$ less than the weight of an equal volume of air; the balloon will therefore rise with a force of $265^{\text{mgr}}\cdot 5$, and may yet be weighted by a network, a light wicker-work boat, and two men. Large balloons are usually made of bands of silk, sewed together, and covered with caoutchouc varnish, which renders the whole air-tight. For small balloons very thin light membranes must be used, if they are to rise. A balloon of 1 litre capacity must have a weight of not quite $0^{\text{gr}}\cdot 625$ if it is to rise, when filled with coal-gas; for 1 litre of water weighs $1,000^{\text{gr}}$, 1 litre of air weighs therefore $\frac{1}{800} \times 1,000 \times 1^{\text{gr}}\cdot 25$, and an equal volume of coal-gas weighs $0^{\text{gr}}\cdot 625$; hence, if the balloon when filled is to be lighter than the displaced air, the envelope must weigh less than $1\cdot 25 - 0\cdot 625 = 0\cdot 625$ grammes. A balloon of the same size, but filled with hydrogen, would, however, rise very well even if the weight of the envelope exceeded 1^{gr} ; for hydrogen weighs less than $\frac{1}{14}$ of air; 1 litre of it therefore weighs not quite $1\cdot 25 \times \frac{1}{14} = 0^{\text{gr}}\cdot 089$; the filled balloon would thus weigh $1^{\text{gr}}\cdot 089$, hence $1\cdot 25 - 1^{\text{gr}}\cdot 089 = 0^{\text{gr}}\cdot 161$ less than the air displaced by it.

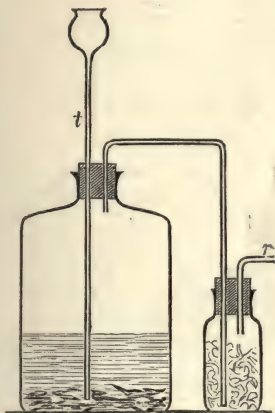
Where coal-gas is accessible, soap-bubbles filled with it may be easily obtained. Pass one end of an india-rubber tube over a burner, (as in fig. 20, page 17), and insert into the other end the tube of a clay tobacco-pipe, or of a small glass funnel which is not more than 3^{cm} wide at the mouth. Dip the mouth of the funnel or of the

pipe into some soap-water contained in a saucer, take it out again and turn the gas on. The liquid film which has formed across the mouth is blown out by the gas into a bubble; when the mouth is turned upwards, and the bubble has a diameter of from 8 to 15^{cm}, it rapidly rises to the ceiling by virtue of its lightness.

If coal-gas cannot be obtained, hydrogen must be made. Hydrogen is one of the constituents of water, and may be prepared by bringing water in contact with zinc and sulphuric acid. The zinc is used in small pieces, such as may be obtained by 'granulating' it in the manner described at page 27, or zinc-clippings may be purchased of a tin-smith and cut up into small pieces. The sulphuric acid must be diluted before it is poured over the zinc. If sulphuric acid is poured into water, considerable heat is evolved; but this heat is much greater when the water is poured into the sulphuric acid. To avoid accidents in consequence of the breaking of the vessel containing the mixture, or the splashing about of the acid, the mixture is best made in the following manner. Pour about 500^{cc} water into a vessel of 1 litre capacity, such as a large stoneware pickle jar, which is placed in a bowl (an earthenware or china washhand-basin) partly filled with water; the water somewhat cools the jar and prevents the escape of the acid in case the jar should break; now pour 50^{cc} sulphuric acid in a small stream into the water, stirring the water continuously with a glass rod. Let the jar remain in the bowl until it is entirely cold, and then transfer the dilute acid into a bottle. Like hydrochloric acid, dilute sulphuric acid produces spots upon articles of clothing; care should therefore be taken in handling it, and spots should immediately be touched with a solution of ammonia carbonate. The concentrated acid has a most destructive action upon textures, and most vegetable and animal substances, which are rapidly decomposed and charred by it. When a drop of it falls upon anything, it should first be wiped off with a piece of dry blotting-paper or an old rag, which should be kept ready for such an emergency; the place should then be immediately washed with a great quantity of water, and finally moistened with ammonia carbonate; but the appearance of a mark can never be entirely prevented.

For the reception of the gas which is generated with effervescence when dilute sulphuric acid is poured over zinc, an apparatus is required of which fig. 154 represents one of the simplest forms. A bottle with a wide neck is provided with a twice perforated cork; through one hole passes the tube-funnel *t*, which reaches nearly to the bottom of the bottle; through the other hole passes a tube bent twice at right angles, one branch of which passes through

the cork of a second smaller glass bottle, and reaches in this also nearly to the bottom. The cork of the smaller bottle has also a second hole through which a short glass tube *r* passes, which is best bent at right angles close to the cork. The corks should be carefully chosen, well softened by hammering, and neatly bored; no luting should be used for them, as they have to be removed every time that gas is to be generated. The smaller vessel serves for purifying the generated gas; for the present purpose it is loosely filled with cotton wool, which retains the small liquid particles which are

FIG. 154 ($\frac{1}{5}$ real size).FIG. 155 ($\frac{2}{5}$ real size).

carried away by the gas while escaping from the generating bottle. About 50^{gr} of zinc in small pieces are thrown into the large bottle; the india-rubber tube for conveying the gas is passed over the end of the tube *r*, the whole is put together, and the dilute acid is finally poured into the bottle through the funnel tube *t*.

The escape of gas is at first rather slow, but the action soon becomes very lively and is accompanied by brisk effervescence, the frothing liquid rising in the bottle; the dilute acid should therefore be poured in very gradually, lest the liquid should pass into the smaller vessel. When the action subsides, a little more dilute acid is poured into the bottle. The generation of the gas should be allowed to proceed for some time, before filling soap-bubbles with it, in order that the air which originally filled all parts of the apparatus may be completely displaced by hydrogen. The mouth of the pipe or funnel should be dipped into the soap-water for a very short time only; if kept too long, a bubble is formed, which, on lifting the mouth of the funnel out of the solution, is deposited upon the surface of it and remains there. The escape of the gas

which is generated in this apparatus, must never be checked by pressing the india-rubber tube with the fingers or closing it by a pinch-cock ; for if not allowed to pass through the india-rubber tube, it will force the liquid in the bottle through the funnel tube. Instead of the latter a glass tube connected with a funnel by means of a short piece of india-rubber tubing, as shown in fig. 155, may be used.

A more perfect apparatus for preparing the gas is represented in fig. 156. It is convenient for many purposes, and possesses the



FIG. 156 (*an. proj.* $\frac{1}{8}$ real size).

advantage that the escape of the gas may be regulated and checked by means of a stop-cock. Two bottles, *a* and *b*, of equal size, are each provided with a short tubule near the bottom, and may be connected by passing the ends of an india-rubber tube over the tubules if they are small enough, or over short pieces of glass tubing fitted into the tubules by perforated india-rubber corks. The bottle *a* is closed by a funnel which is placed loosely in the neck so as to prevent the liquid spirting out ; the bottle *b* is closed tightly by an india-rubber stopper, through which a short glass tube passes. The tube *t* which serves as drying tube is filled with cotton ; it is fixed by thread to the neck of the bottle *b*, and is closed at one end by an india-rubber stopper with a short glass tube through it, and may thus be connected with the bottle by an india-rubber tube ; a stopcock *h*, which has a short nozzle for attaching an india-rubber tube to it, is fixed to the other end. The drying tube has a bulb at one end not filled with cotton, in which the greater part of the moisture carried over by the gas collects, so that the cotton in the tube does not require frequent changing. A layer of small pebbles, sufficient to reach about 1 or 2^{cm} above the lateral orifice, is first placed at the bottom of

the bottle *b*; upon this layer the zinc is placed; the bottle *a* is filled to about three-fourths with dilute acid, and then placed upon a support consisting of small wooden blocks. Such blocks are frequently used for supporting and adjusting the heights of apparatus, and a number of them, 10 to 16^{cm} square, and varying in thickness from 1 to 4^{cm}, should be obtained from a joiner.

As long as the stop-cock *h* is closed, no acid can pass from *a* to *b*, because the space in *b* is filled with air (art. 2); but if the stop-cock is opened, the air can escape, acid from *a* reaches the zinc in *b*, and hydrogen is generated. If the stop-cock is again closed, either completely or so much that less gas escapes than is generated, then the pressure of the gas in *b* will drive the liquid back into *a*. When the liquid in *b* has sunk below the lateral orifice, then gas passes through the connecting tube into *a*, and if the zinc were placed immediately upon the bottom of *b*, the generation of gas would go on and the generated gas would be wasted by escaping through the bottle *a*; this is prevented by the layer of pebbles which is interposed between the acid at the bottom of the bottle and the zinc; as soon therefore as *b* is filled with gas, the further generation of it ceases. The zinc remains somewhat moistened by the acid, and hence for some time after the liquid in *b* has sunk below the tubule, bubbles of gas escape with a loud gurgling sound through the tube into *a*; but only a little gas is thus wasted and the apparatus affords a much more economical means of preparing the necessary quantity of gas than the apparatus shown in fig. 154. The zinc is dissolved by the acid and combines with it to form a salt, the so-called 'white vitriol' (zinc sulphate); if the saturated solution be allowed to evaporate in the air, the zinc sulphate separates from it in crystals. When the acid is saturated, that is when no more zinc is dissolved by it, it must be replaced by a fresh supply.

Small balloons are made of goldbeater's skin and latterly also often of 'collodion.' If gun-cotton is dissolved in ether and a thin layer of the solution be spread over a surface of glass and dried, the gun-cotton appears as a thin film; to the solution and to films formed by it the name of collodion has been given. If a glass flask is rinsed with collodion the film formed after drying appears in the form of a small balloon, but it is not advisable to attempt making a balloon in this manner. The collodion must be prepared with special care and thoroughly free from water, or else the balloon cannot be got out of the flask without tearing; the common commercial collodion is not fit for making balloons, and it is better to buy them. To fill a balloon with hydrogen, it is carefully pressed between the palms of the hands, in order to remove the air

from it as much as possible, and a piece of glass tube connected by an india-rubber tube with the generating bottle is inserted into the mouth. A thread wound loosely round the neck of the balloon and not too firmly tied, holds the balloon sufficiently firm to the glass tube for the purpose of filling it with gas. When quite distended by the latter the balloon is detached by unwinding the thread and, if necessary, by pushing it along the tube by a gentle pressure of the fingers. When detached it rises to the ceiling and remains there, until by the escape of hydrogen and the influx of air the weight of the balloon exceeds that of the displaced air. It is not advisable to tie thread around its neck in order to prevent the escape of the hydrogen from the balloon and to maintain it longer in the air, for the balloon is easily damaged by it. Collodion balloons rise also when filled with coal gas, provided they are not too small.

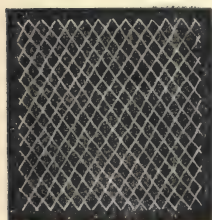
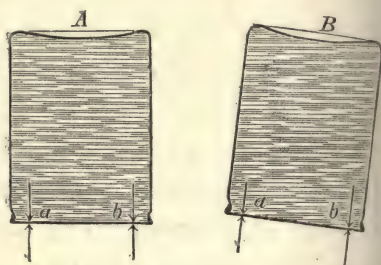
Hot air is lighter than cold air, as will be seen further on; a balloon may hence be made to rise by filling it with hot air. Such a balloon must, however, be of rather large size, and have a wide aperture at the lower part, where a fire is kept up, usually a spirit flame, or in very large balloons by burning straw, in order to heat the air in the interior. Such balloons are usually made of thin paper, and have a size of one or more metres; they cannot be well used in a room, and in the open air they are very dangerous if they should come into contact with combustible objects.

✓ 25. *Atmospheric pressure. The Barometer.*—If a tumbler with a smooth edge is filled with water and covered with a piece of stiff paper, it may be inverted, mouth downwards, and no water will run out. If the paper touches the edge all round very closely the experiment will often succeed when the tumbler is simply inclined rather gradually and finally inverted, but it is safer to press against the paper with the fingers of one hand spread out, or better with a flat body such as a small board or a plate, until the mouth of the tumbler is turned downwards; the hand or other object used for holding the paper is then removed, and it will be found that the paper adheres, and that no liquid, or at most a small quantity only, runs out.

It is *the pressure of the atmosphere* which causes the water to remain in the vessel, in apparent opposition to the action of gravity. Atmospheric air has weight, and, like a liquid, it exerts, in virtue of its weight, a certain pressure upon all bodies immersed in it. Now, although the specific gravity of air is very small, the pressure which the air exerts is very considerable, because the atmosphere reaches to an immense height, or, in other words, because the surface of the solid earth is the bottom of an ocean of air which has an enormous depth.

The pressure of a gas agrees also in this particular with that of a liquid, that at any point the pressure is equal in all directions; a surface turned upwards is pressed downwards with the same pressure with which that surface is pressed upwards when it is directed downwards: this is the case with the pressure upon the surface of the paper. The paper prevents the escape of water at one point and the entrance of air at another, which would happen if the surface of the water were not perfectly horizontal; but it is impossible to maintain that surface horizontal without the paper. That the paper is not, in this case, a kind of lid used for confining the water in the vessel, may be easily proved by tying a piece of 'bobbin-net,' having its meshes as wide as shown in fig. 157, or even a little wider, over a jar of about 0.5 or 1 litre capacity. The jar may then be filled with liquid and emptied again just as if no net were tied over it; but if it is quite filled with water, covered with a plate, and inverted so as to keep the mouth as horizontal as possible, the plate may be removed, and the water will

remain in the vessel, maintained by atmospheric pressure, as long as the mouth is kept horizontal, that is, as long as at all points the pressure of the air and that of the water are in equilibrium, as shown in fig. 158 *A*; but if the jar be held somewhat inclined, as in 158 *B*, then the depth of the liquid particles varies from point to point; at *a* the downward pressure of water

FIG. 157 (*real size*).FIG. 158 ($\frac{1}{2}$ *real size*).

is less than the upward pressure of the atmosphere, at *b* it is greater, hence the air forces its way into the vessel at *a*, while the water drops out of it at *b*.

FIG. 159
($\frac{1}{10}$ *real size*)

If a bottle which is quite full be closed with the finger and inverted into a vessel containing water, as in fig. 159, no water will leave the bottle when the finger is withdrawn; for the pressure of the air upon the surface of the water in the tumbler is transmitted through the liquid in all directions and maintains the water in the bottle. If the latter has a narrow neck (5^{mm} or less, as in a small medicine bottle), the water and air cannot conveniently pass by one another, and the water will remain in the bottle even if the mouth is not immersed.

The pressure of the air is so considerable that,

instead of small bottles, very tall vessels might be used; but if the height of the vessel were to exceed 10^m , which is about the height of a house of moderate size, the pressure of the air would be incapable of supporting the whole of the liquid. This may be proved by the apparatus represented in fig. 160. A number of glass tubes are joined by connecting pieces of brass, and form a tube of about 12^m length, which is fixed to a wall sufficiently high, or kept in a vertical position by means of a scaffolding specially erected for the purpose. Both ends are provided with stop-cocks, the upper end also with a funnel; the lower end dips in a vessel with water. At first both stop-cocks are open, and the water in the tube is hence at the same level as that in the vessel, which is marked 0 in the figure. The lower stop-cock is then closed, the tube is filled with water through the funnel, and when it is full the upper stop-cock is closed. When the lower stop-cock is opened, some of the water will run out of the tube into the vessel, but a column of water will remain in the tube, having a length of about 10^m , measured from the level of the water in the lower vessel to the top of the column, as shown in the figure. *The pressure of the atmosphere is capable of supporting a column of water 10^m high, or, the pressure of a column of water of this height is equal to the pressure of the atmosphere.*

The pressure of the atmosphere may be more conveniently measured if, instead of water, mercury is employed; mercury is much heavier than water, and a smaller column will therefore balance the atmospheric pressure. A glass tube closed at one end, 80^{cm} long and about 5^{mm} wide, is filled with mercury; the open

end is closed with the finger, the tube is inverted and the mouth dipped into a vessel of mercury; the finger is then withdrawn. As long as the tube is kept

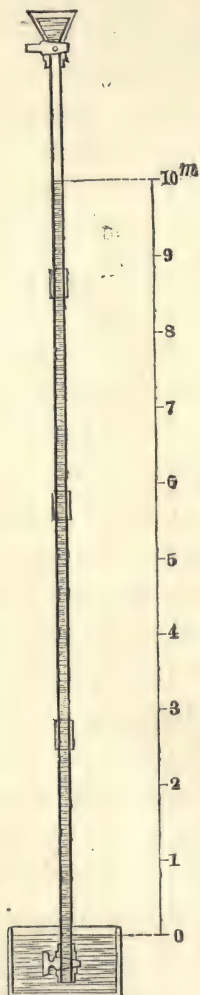


FIG. 160 ($\frac{1}{100}$ real size).



FIG. 161 ($\frac{1}{10}$ real size).

inclined, so that the upper end is not more than about 70^{cm} above the level of the mercury in the vessel,

the tube remains filled with mercury, but as soon as the tube is placed in a vertical position the mercury leaves the upper end and forms a column which has a height of somewhat more than 70^{cm}, as shown in fig. 161.

A contrivance for measuring the atmospheric pressure is called a *barometer*. Fig. 160 represents a *water-barometer*, fig. 161 a *mercurial barometer*. The former kind is very rarely used, the latter most frequently. Observations made at different places prove that the height of the column is not everywhere the same; the pressure of the atmosphere is therefore different in different localities. These differences arise from the irregularities in the earth's surface; the bottom of the aërial ocean is not even, but some regions are elevated, some depressed, and since in the air as in a liquid the pressure increases with the depth, because the upper layers press upon those below, it follows that the pressure of the atmosphere is greater on the plain and in valleys than upon hills and mountains.

The lowest regions on the earth's surface are those situated along the sea-coast; at these localities the mercurial column indicates therefore the greatest pressure. The average pressure at the level of the ocean is about 760^{mm}, and the height of the column decreases by 1^{mm} for every 11^m which the barometer is carried higher; thus at a place which is 330^m above the level of the sea, the average height of the column is $760 - \frac{330}{11} = 730^{\text{mm}}$. When the barometer is observed in the same place for some time daily, variations in the

height of the column are seen to take place, which have a range of about 50^{mm}. If the atmosphere were not subject to violent movements, the height of the barometer at the same place would be pretty constant, and it would be always the same if the atmosphere were perfectly at rest. But causes, which will be considered further on in the chapter on HEAT, produce great atmospheric currents, gales, and winds; these sweep over vast areas and disturb the equilibrium of the atmosphere: hence arise the continual fluctuations of the atmospheric pressure.

The tube may be prepared from a piece of glass tubing, somewhat more than 80^{cm} long, which is drawn out into a short point near one end; the point is then closed and rounded off over the spirit-flame with the blow-pipe, turning the tube constantly between the fingers of the left hand, in order to prevent the tube being melted at one side more than at another. The heated end is apt to crack, especially when the glass is thick, unless it be very slowly cooled; this is done by keeping the end in the flame for some time, turning it constantly, and raising it gradually higher and higher above the flame until it is nearly cooled. The sharp edge of the open end should be rounded off in the spirit-flame. A very clean and dry tube should be selected, as it is difficult to clean it afterwards, when one end is closed; a tube open at both ends may be cleaned by passing through it a piece of twine (if necessary with the help of a long wire) and tying to the end of the string a small piece of linen; the latter is then repeatedly drawn through the tube. As in every flame vapour of water is formed, some moisture will generally enter the tube while the open end is held in the spirit-flame. The tube should be dried in the following manner. Heat the barometer tube by moving it several times to and fro over the spirit-lamp, or by holding it in a horizontal position before a large kitchen fire; introduce into it nearly up to the closed end a very narrow glass tube, 85 or 90^{cm} long, and suck at the projecting end of the narrow tube; a current of air is thus passed through the barometer tube which removes the moisture.

Air-bubbles are apt to remain between the glass and the mercury, when the latter is poured in; they rise gradually to the top after the tube has been inverted, and in virtue of the expansive

force of gases they exert a pressure upon the mercurial column, making the height of the latter appear less than that really due to atmospheric pressure. The tube should be filled by means of a small funnel of folded paper to about 2^{cm} from the open end; this is firmly closed by the finger, and the tube is slowly inclined up and down, thus moving the large air-bubble which has been purposely left up and down along the sides of the tube; the small bubbles along the sides are swept off by this operation and join the larger one; finally the tube is completely filled to the open end. It is thus possible to remove, if not all, at least the larger bubbles. In a wider tube, of about 1^{cm} width, the operation is more successful, and such a tube has also the advantage that the action of capillarity produces a scarcely sensible error, while in narrow tubes it causes a depression of the mercurial column below its real height. A tube 80^{cm} long and 1^{cm} wide requires, however, more than 850^{gr} of

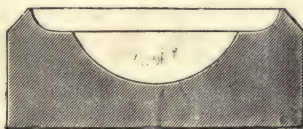


FIG. 162 ($\frac{1}{2}$ real size).

mercury, and as a quantity of mercury is required for the vessel in which the tube dips, it will be more expedient to make use of a narrower tube. Fig. 162 is the section of a very convenient shape for the vessel required in this experiment. It should be made of iron or stone ware, and will be found useful for other experiments.

The height is measured by means of a wooden scale, divided into centimetres. Obtain from a joiner a rectangular bar, made of dry, hard wood, 1^m long, 1^{cm} broad, and 5^{mm} thick, and paint it white on one side. When thoroughly dry, the whole painted length is divided by pencil lines with the help of a metre rule into square centimetres. The first, third, fifth, and all odd-numbered squares are left white, every tenth square is painted red, and all the other even-numbered squares are painted black. In fig. 163 the red is indicated by oblique lines across the square. A scale of this kind is very convenient where great accuracy is of less importance than distinctness of the graduation. The difference in the colours renders any number of centimetres discernible even at some distance, without figures on the scale. Small quantities of the necessary paints may be bought at a very little expense, ready for use, of any oil and colourman.' Or the student may purchase the materials

and mix the paints himself. The following are the requisite ingredients and their proportions,—

Parts.	White	Pts.	Red	Pts.	Black
$\frac{5}{8}$	White lead	$\frac{5}{8}$	Chinese red (or red lead)	$\frac{5}{8}$	Vegetable black
$\frac{1}{8}$	Dryers (litharge)	$\frac{1}{8}$	Dryers	$\frac{1}{8}$	Dryers
$\frac{3}{16}$	Linseed oil	$\frac{3}{16}$	Linseed oil	$\frac{3}{16}$	Linseed oil
$\frac{1}{16}$	Spirits of turpentine (turps)	$\frac{1}{16}$	Turps	$\frac{1}{16}$	Turps.

The solid materials must be in a finely powdered state; they are thrown first in the vessel, in which the paint is made up, and the liquids are poured in afterwards on the top. The whole is then well stirred until the mass is of uniform consistence.

The so-called 'black-japan' may also be used as a black varnish, and a red varnish may be made by dissolving a bit of sealing-wax in spirits of wine. The brushes may be cleaned with oil of turpentine; or, if any varnish has been used, with a little spirits of wine.

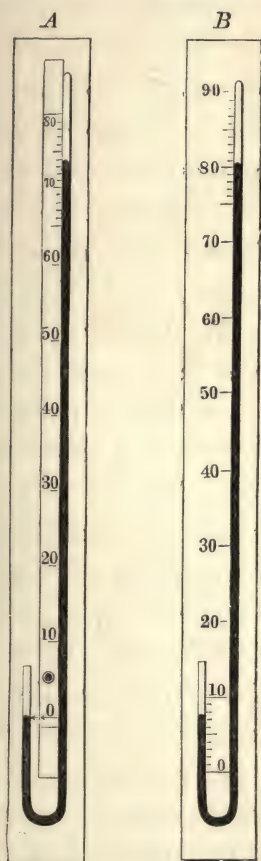
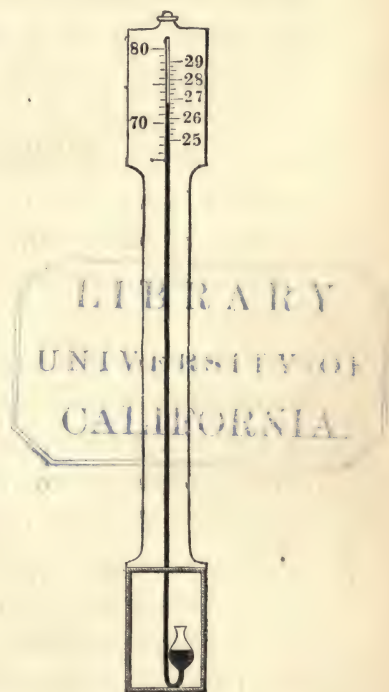


FIG. 163 ($\frac{2}{3}$ real size).

When the tube is to be removed, it must be inclined very cautiously, otherwise the mercury may strike so hard against the closed end as to break it off.

A barometer which is to be used not for a single experiment, but for repeated accurate measurements of the atmospheric pressure, must be specially constructed for the purpose. Barometers in which the tube dips into a vessel containing mercury are called *cistern-barometers*; in another class of barometers the tube is bent upwards near the open end, as seen in fig. 164; these are called *siphon-barometers*. The siphon-barometer is more convenient for transport when observations are to be made at different places, and the error arising from capillarity is excluded if both branches of the tube are equally wide, for in that case capillarity depresses both ends of the mercury equally, and the length of the mercurial column, that

is, the vertical distance between the tops of the mercury in both branches of the tube, remains unaffected by the action of capillarity. It will be evident that in a siphon-barometer any change in the atmospheric pressure affects the mercury in both branches

FIG. 164 ($\frac{1}{10}$ real size).FIG. 165 ($\frac{1}{10}$ real size).

simultaneously; hence the scale is either moveable and allows of the zero-point being placed on a level with the lower surface of the mercury, as shown in fig. 164 A; or the zero-point is placed somewhere between the two

branches of the tube, and beneath the lowest position to which the mercury in the shorter branch can ever fall, as shown in fig. 164 *B*; the height above the zero-point of the mercury in each branch is read off on the scale, and the difference of the two readings gives the length of the mercurial column which the pressure of the atmosphere supports.

Common barometers, or so-called 'weather-glasses,' are mostly unfit for accurate observations on atmospheric pressure; the tube in most barometers of this kind is too narrow, and the column is hence depressed by capillarity. In fig. 165 the usual form of such weather-glasses is represented, and the narrowness of the tube indicated. By measurement of the height of the column with a metre-rule and comparison of the length found with the indications of a correct barometer at the same time, this error may easily be detected, and it will then be seen that the scale-divisions given at the top of such barometers are quite incorrect. Many barometers have, as shown in fig. 165, two scales, one on each side, each being divided according to a different unit. In the figure the left-hand scale gives the length of the column in centimetres, the right-hand scale in Paris inches.

The empty space at the top of the tube is called the *Toricellian vacuum*, after Toricelli, who was the first to make an experiment on atmospheric pressure with the barometer. To obtain a perfect Toricellian vacuum (and this is absolutely indispensable in a trustworthy barometer), the mercury must not only be treated with particular care, before filling the tube,

but it must be boiled in it for some time, so that every trace of air may be swept out by the vapour of mercury which is formed when the latter is boiled. The construction of a good barometer is difficult, and can only be undertaken by skilful and experienced workmen.

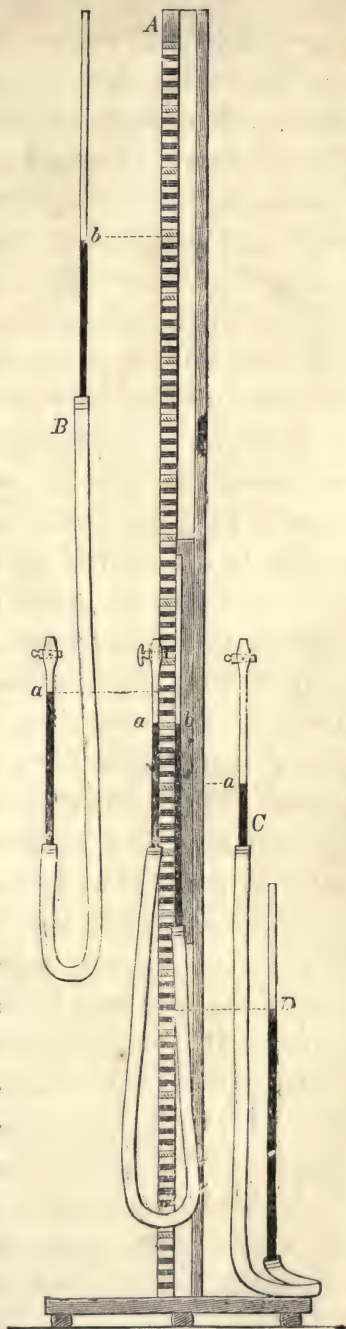
A kind of barometer which is much more portable than the long tubes of the mercurial barometer, and less liable to be broken, has recently come into use under the name *Aneroid-barometer*. The essential part of this barometer is an elastic metallic chamber, either in the form of a flat box or of a short tube, which has been exhausted of its air and hermetically closed: if the pressure of the air increases, the chamber is somewhat compressed; if the pressure diminishes the chamber expands, and these variations are transmitted by a system of wheels and levers to a pointer, which travels over a dial; the dial is graduated by comparison with a mercurial barometer.

The height of the mercurial column supported by the atmospheric pressure being known, the weight can be calculated which is equal to that pressure upon a given surface. The pressure upon a square centimetre is equal to the weight of a volume of mercury of 76^{cc} , that is, it equals $76 \times 13.6 = 1033^{\text{gr}}.6$ or about $1^{\text{kg}}.$ The body of a man has on an average a surface of 15,000 square centimetres: the pressure of the atmosphere upon it is therefore $15,000^{\text{kg}}$, or nearly 15 tons. Such an enormous pressure might seem impossible to be borne, but it must be remembered that the pressures are everywhere equal, but act at opposite sides in contrary directions and hence counterbalance one another. It might also be supposed that the effect of this force would

be to press the body together and crush it. But the soft fleshy parts of the body are everywhere penetrated by liquids, which are incompressible, while the cavities of the body, as the mouth, lungs, ears, are virtually in connection with the external air: the internal pressure is therefore the same as the external. Finally, the solid parts of the skeleton are sufficiently strong to resist even a higher pressure. The effect of atmospheric pressure upon the human body is only rendered sensible when it is removed from any part. If the mouth of a small glass-funnel (3 or 4^{cm} in diameter) be firmly pressed upon the back of the hand, or the fleshy part of the arm, and the air sucked by the mouth out of the funnel, the pressure of the air upon the surface covered by the funnel becomes diminished, the external pressure distends the skin and raises it, while at the same time the blood is driven to the part where there is less pressure, and it is reddened.

26. *Mariotte's Law.* It has been shown in art. 3, that gases alter their volume if the pressure varies, and it remains now to investigate more closely the relation between the volume of a gas and the pressure upon it. Experiments on these relations may be made by an apparatus of which fig. 166 represents the most essential parts. Two glass tubes, *a* and *b*, are connected by a stout india-rubber tube, which is additionally strengthened by being covered with wool or cotton fabric; the tube *a* can be closed by a well-ground air-tight stop-cock of glass, the tube *b* is open at the top; *a* is fixed permanently along a wooden scale, *b* is attached to a bar which slides in a groove by the side of the scale, and may be fixed at any point of it;

the contrivance for sliding and clamping *b* along the scale is not shown in the figure, in order to avoid confusion. The india-rubber tube and part of the glass tubes are filled with mercury. To begin the experiments the stop-cock of *a* is opened, and *b* is clamped so that the top of the column in both tubes is opposite to the same division of the scale, for example at 90^{cm} , as in fig. 166 *A*. Both tubes being now open, the atmosphere presses equally upon the mercury in them, and let this pressure be 74^{cm} at the time of the experiment, that is, let a column of mercury 74^{cm} high counterbalance the pressure of the atmosphere at that time. If now the stopcock of the tube *a* be closed, there remains in the tube, at the top of the mercury, a column of air (represented in the figure as 10^{cm} long, viz. reaching from 90 to 100^{cm} of the scale); this column is still under the pressure of the

FIG. 166 ($\frac{1}{10}$ real size).

atmosphere. The tube b is now made to slide upwards, and clamped so that the top of the mercury in it is opposite to the division 169^{cm} of the scale, as in fig. 166 B . The air above the mercury in a is now not only under the pressure of the atmosphere, but it has to bear the additional pressure of the raised column of mercury, and is therefore compressed. It will be found that the column on the left side, in a , rises to 95^{cm} , when that at the right side, in b , stands at 169^{cm} . It follows that the volume of air in a is diminished by one half, and supports an additional pressure of $169 - 95 = 74^{\text{cm}}$, or, since the pressure of the external atmosphere is also 74^{cm} , the air in a is now under a pressure which is double of what it was originally. If b is now made to slide downwards, and the top of the column reaches again 90^{cm} , the column in a is also at 90^{cm} , and the volume of the air above the mercury in it has again increased. When b slides lower down than 90^{cm} , the mercury in a also falls below 90^{cm} but not so far as that in b is lowered; for example, if b be now clamped, so that the mercury in it stands at 43^{cm} , as shown in fig. 166 C , the mercury in a will stand at 80^{cm} . Evidently in this position of the two columns, the pressure of the air above the mercury in a must be less than the pressure of the external air upon the column in b ; the difference in the height of the two columns is $80 - 43 = 37^{\text{cm}}$, the pressure therefore in a must be less by 37^{cm} than the atmospheric pressure which acts in b , that is, the air in a is now under a pressure of $74 - 37 = 37^{\text{cm}}$, or the pressure is half of what it was originally. These two experiments demonstrate, that

if the pressure is doubled, the volume of the enclosed air is diminished to one half; and that if the pressure is reduced to one half, the volume is doubled. If experiments are made at various pressures, the general law is proved that: *The volume of a gas decreases in the same proportion as that in which the pressure upon it increases, and it increases in the same proportion as that in which the pressure decreases*; or, more briefly, *The pressure and volume of a gaseous mass are inversely proportional*.

This law is usually called *Mariotte's Law*; it holds good for all 'permanent' gases, that is, those which have not yet been liquefied by pressure, as oxygen, nitrogen, atmospheric air, etc. But some gases—for example, carbonic acid, ammoniacal gas, etc.—are 'coërcible,' that is, they may be liquefied by pressure; such gaseous bodies manifest considerable deviations from the law.

The following experiments on Mariotte's law, though less striking, are more easily performed than those just described.

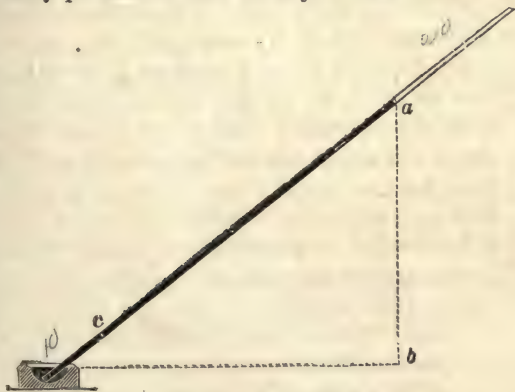


FIG. 167 ($\frac{1}{10}$ real size).

Take a glass tube, the same as that used for the barometer experiment (p. 232, fig. 161), provided its bore is of pretty uniform width throughout. Measure off 10^{cm} from the open, and 20^{cm} from the

closed end, and mark these distances by a small strip of paper pasted upon the tube, as shown in fig. 167. Fill the tube with mercury up to the mark near the open end, thus leaving in it a column of air 10^{cm} long, under the pressure of the atmosphere. Close the end with the finger, invert the tube, and immerse the lower end in a vessel containing mercury, precisely as in the barometer experiment. Remove the finger and incline the tube until the top of the mercury stands at the upper mark. The volume of the air in the tube is now doubled, for it is 20^{cm} long, and the perpendicular height of the mercury in the tube will now be represented by the length ab , which will be found to be half the height of the barometer at the time, that is, the mercury stands twice as high in a tube having no air at the top, as in the tube having air above the mercury; this air therefore evidently exerts a pressure which is half of that of the atmosphere, that is, the pressure is diminished to one half, when the volume has become twice as great as it was originally.

Draw out one end of a dry glass tube, 60^{cm} or 70^{cm} long, and 2^{mm} wide, into a fine aperture. Immerse the other end in mercury and,

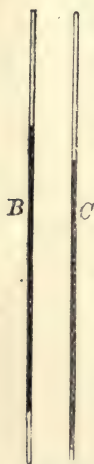


Fig. 168
(real size).

A



taking care that no moisture enters the tube, suck up into it a thread of mercury equal in length to about half the average height of the barometer; if the latter is 74^{cm}, make the length of the thread of mercury 37^{cm}. Move the thread, by cautiously tapping or inclining the tube, until its end is about 10^{cm} distant from the fine aperture, as in fig. 168 A, and close the end with the blowpipe, taking great care to direct the flame well across the end to be closed, and not upon the tube itself, so as not to heat the air in it, which would in that case expand and partly escape from the tube before it is closed. To maintain the thread in the required position, place the tube upon a table, let the fine aperture project about 10^{cm} from the edge, take the lamp in your left hand, the blow-pipe in the right, and close

the end without moving the tube.

When cool hold the tube in a vertical position, the open end being first at the top, fig. 168 B. The enclosed air will now be compressed to two-thirds of its previous volume, for in this position it has to bear, in addition to the pressure of the

atmosphere, the weight of a column of mercury which is equal to half the atmospheric pressure: the whole pressure upon the enclosed air is $\frac{3}{2}$ times the atmospheric pressure, and the volume, being diminished in the inverse proportion, is now $\frac{2}{3}$ of the original volume. Now turn the tube round, and hold the closed end uppermost, fig. 168 C. In this position the external pressure balances both the weight of the mercury and the pressure of the air enclosed at the top of the tube; but as the mercurial column represents half the pressure of the atmosphere, the enclosed air has now to bear only the remaining half of the atmospheric pressure: it will be found that in this position the volume of the air in the tube is double of what it was originally.

The specific gravity of air is altered by expansion or compression. A litre of air, that is, $1,000^{\text{cc}}$, weighs, under ordinary circumstances, $\frac{1,000}{800} = 1^{\text{gr}}.25$, the specific gravity of air being $\frac{1}{800}$. If the same air be exposed to double the pressure, its volume will be 500^{cc} , and 1^{cc} will now weigh $\frac{1.25}{500} = 0^{\text{gr}}.0025 = \frac{1}{400} = \frac{2}{800}$ gramme; the specific gravity of the air has, therefore, been doubled. Hence generally, while the volume of a gas is inversely proportional to the pressure, *the specific gravity of a gas is directly proportional to the pressure.*

The pressure of the atmosphere becomes less as the height above the level of the sea increases, and the specific gravity of the air becomes therefore less the higher we ascend in the atmosphere. The rule given on page 233 for estimating the elevation above the surface by the depression of the mercurial column is therefore not strictly correct, and is only approximately correct for inconsiderable heights. For although a column of air on the surface 11^{m} high exerts a pressure which is equal to that of a column of mercury 1^{mm} high, it will at a greater elevation, in consequence of the gradual diminution of the specific gravity, require

a longer column of air to have the same weight and to exert the same pressure. The diminution of the pressure as we ascend in the atmosphere is therefore not uniform, but proceeds at a rate which gets continually slower and slower, and can only be exactly determined by taking all circumstances of the case into consideration. The calculation required for this purpose would exceed the scope of this work; but not only can the diminution of the atmospheric pressure from one point to a higher one be precisely calculated, but, conversely, from the observed difference in the atmospheric pressure at two places the difference in their heights may be determined. On this fact rests the application of the barometer to the measurement of heights.

27. *Applications of Atmospheric Pressure and of Mariotte's Law.*—The pressure and elasticity of the air, varying in accordance with Mariotte's law, are applied in a variety of mechanical contrivances, depending on the mutual action of gases and liquids, or of gases, liquids, and solid bodies.

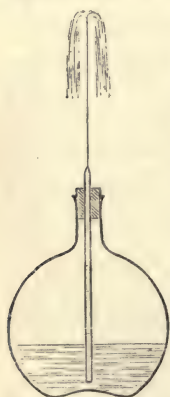


Fig. 169 is a flask or balloon of glass, containing air and water, the latter filling about one third, or one half of the flask. The neck is closed by a cork through which passes a tube, which reaches nearly to the bottom of the flask; the projecting end of the tube is drawn out to a fine aperture. If the air in the flask is compressed by blowing strongly into the tube, and the latter is then withdrawn

FIG. 169 ($\frac{1}{2}$ real size). from the mouth, a jet of water issues from the tube which has at first a height of perhaps 1^m or more, but gradually diminishes in height until

it ceases entirely. This is due to the pressure of the air enclosed in the flask; while the water is driven out of the tube, the air gradually expands, and the pressure diminishes until it is again equal to the atmospheric pressure; then no more water issues from the tube. The washing bottle, fig. 36, differs from the apparatus just described in having an additional tube, which allows air to be blown into it, while the jet of water issues from the spout; the jet may thus be maintained for a considerable time.

The apparatus may easily be put together by means of a piece of tubing, drawn out at one end, a cork, and a bottle which may, of course, have a different shape from that in fig. 169; the tube should be a few millimetres wide, but at the point only from 0^{mm}.5 to 1^{mm}. The flask may be filled either by removing the cork, or by sucking at the tube, and thus rarefying the air in the flask; if the tube is then closed and opened under water, the pressure of air outside the flask is greater than inside, and water is driven into the flask until the pressure of the air in it equals the atmospheric pressure. If the quantity of water which has entered is not sufficient, the sucking may be repeated, but the flask must now be held upside down, for otherwise the end of the tube might dip into the water, and no air, but water, would then be extracted from the flask.

If the air in the flask is compressed by the pressure of a column of water, the apparatus becomes a *Hero's Fountain*. In fig. 170 *A*, there are two tubes, *c* and *d*, one of which, *c*, leads from the bottom of the flat dish *ee* on the top of the vessel *a* to the lower part of the vessel *b*, while the tube *d* leads from the top of *b* to the upper part of *a*. A third tube, *f*, passes through the flat dish *ee* to the lower part of the vessel *a*; this tube can either be taken out, as is the case in the ornamental applications of this kind of fountain, where the whole is usually fixed to the floor, and *a*

may then be filled by simply removing *f*; or water may be poured into the shallow dish and allowed to run down through *c* into *b*; the whole apparatus is then inverted and the water passes from *b* through *d* into *a*. When the upper vessel is thus filled, water is poured into the shallow dish; it flows through *c* into *b*, and the pressure of this column of water, acting upon

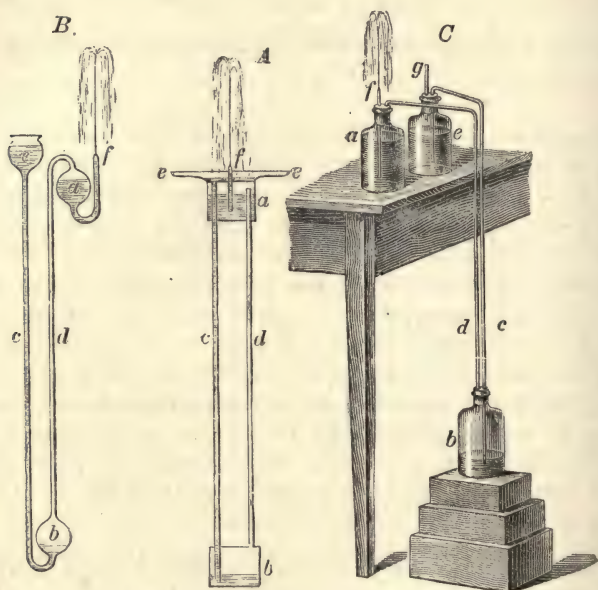


FIG. 170 (*A, B*, $\frac{1}{16}$ real size; *C*, an. proj., $\frac{1}{16}$ real size).

the air in *b*, is transmitted through *d* to the top of *a*, where it acts upon the water and makes it jet out; the height of the jet is represented in the figure as much less than it actually is; for if it were not for the resistance of the atmosphere and the friction, the liquid would rise to a height above the surface of the water in the dish equal to the difference in the level of the water in *a* and *b*. When the water in *a* sinks below

the lower end of *f*, the jet ceases, and only a little air is then ejected through the spout. At last, the water from *a* having passed into the dish, and thence into *b*, the vessel *b* is nearly filled. The apparatus may then be inverted and the water allowed to flow back again into *a*, or, as is the case in the fixed fountains, *b* may be emptied by a stop-cock at the side, and *a* filled again by removing *f*.

Fig. 170 *B* represents a fountain made entirely of glass; *a*, *b*, *c*, *d*, and *f* correspond to those parts in *A* which are lettered similarly, and the funnel *e* replaces the flat dish *ee* in fig *A*. The funnel should be at least as capacious as *a* or *b*, because in this form of the apparatus the jet does not fall back into it. The vessel *b* is filled through the funnel *e*, the whole is inverted, the water thus fills *a*, and water is then poured into *e*.

Fig. 170 *C* shows a Hero's fountain, which may be easily constructed by means of glass bottles, tubing and corks. The several parts have again the same letters; the bottle *e* serves in place of the funnel in *B*, and the parts *a*, *b*, *c*, *d*, and *f*, correspond to the parts marked by the same letters in *A* and *B*. The bottle *e* is tightly closed by a cork through which passes the short tube *g* and the long tube *c*, which is continued downwards; by blowing through the short tube, the water is made to flow from *e* through *c* into the bottle *b*, and the flow continues even when no more air is blown in; the tube *c* acts now like a siphon, the action of which will be explained immediately. The apparatus cannot be carried about as a whole, nor set up without a proper support; the bottles *a* and *e* should be placed near the edge of the table, and *b* upon a support of the right height, or otherwise the putting together and the taking to pieces of the apparatus is very difficult. First fill *a* and *e*, close them with their corks, and place both so that the tubes *c* and *d* are very near to one another; next push the cork for *b* over the tube *c* until it is opposite to *d*, seize both tubes with the left hand just above the cork, and push the latter with the right hand over the end of *d*; now press the cork into the mouth of *b*, and place the latter upon the supports which have been kept in readiness. The apparatus is, of course, taken to pieces in inverted order.

The explanation of the phenomena which take place when liquid and gaseous bodies act mechanically

upon one another is in most cases very simple, if we recollect that in a liquid the pressure increases from above downwards, and decreases from below upwards; that in the same horizontal layer the pressure is everywhere the same; and that at any given point in a liquid, in consequence of the great mobility of the liquid molecules, the pressure is the same in all directions; further, that in gaseous bodies the pressure likewise increases from above downwards, but that, in consequence of the low specific gravities of gases, the difference of pressure at different altitudes is very inconsiderable unless the difference of the altitudes is very great. The difference of pressure at the top and base of a mass of air which has a height of several centimetres, or even of several metres, is so small, that no sensible error is committed if the difference of pressure is altogether neglected, and the pressure at the base assumed to be the same as at the top.

Fig. 171 represents a tube, $abcd$, bent twice at

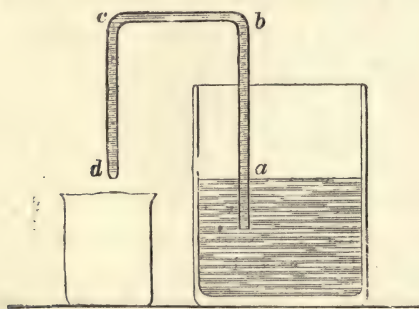


FIG. 171 ($\frac{1}{4}$ real size).

right angles and open at both ends. Suppose the tube to be filled with water and its longer branch immersed in water so that the other end d is at the same height

as the surface of the water in a . The considerable pressure exerted by the atmosphere upon the surface of the water is transmitted downwards, and in the interior of the liquid the pressure increases, so that at the extremity of the immersed branch of the tube the pressure is somewhat greater than at the surface. The water is there pressed upwards into the tube. Within the tube the pressure at first gradually decreases; at a it is equal to the pressure outside, that is, to the atmospheric pressure; at b it is less, and from b to c it remains the same; but from c downwards it increases, and at d it is again equal to the external pressure. The pressure of the water and of the air at d are thus in equilibrium; no water will leave the tube, nor will the air enter it. If the tube is somewhat raised, so that d is higher than the surface of the water, the pressure of the water at d becomes less than that of the air, the latter overcomes the former and air enters the tube, while the water is driven back; if, on the contrary, the tube is lowered in the water so that d is lower than a , the pressure of the water at d is greater than that of the air, and water begins to flow out of the tube until the surface of the water in the vessel is again at the same height as d ; the pressure of the air upon the surface of the water continually drives water into the tube to replace that which has run out at d .

A tube about 4^{mm} wide, and from 25^{cm} to 30^{cm} long, is bent in the form shown in fig. 171; the ends should be made smooth and straight before bending the tube. It may be filled by immersing it completely in a capacious vessel full of water, or the tube is held with the open ends upwards, and water is poured into the longer branch until the shorter is filled; the end of the shorter branch is

then closed with the finger and the longer branch filled. When the tube is full, both ends are closed with the fingers, the tube is inverted, the longer branch dipped into water, the finger withdrawn from that end, and the tube clamped in the retort-stand, so that the end of the shorter branch is somewhat lower than the surface of the liquid; the finger is then withdrawn from the other end also. Water will run out from that end, but it will cease to flow when the surface at *a* has sunk to *d*; if the aperture is horizontal, the water remains within the tube. If now the tube be lowered in the retort-stand, the flow of water commences again; but if *d* be raised ever so little above *a*, the water flows back into the vessel.

The vessel which contains the water may also be placed near the edge of a table so that *d* projects beyond it, and the tube may be filled by simply applying the lips at the end *d* and sucking; the pressure of the air in the tube is diminished by suction, and the external pressure drives the water into the tube.

A tube, bent as shown in fig. 171, and used for transferring a liquid over the sides of vessels, or any other small elevation, is called a *siphon*. Its shape often resembles a U or V, and the two branches may be of equal or different lengths. If a liquid is to be completely removed from a vessel, the longer branch of the siphon must be outside the vessel, for only in this case the end of the external branch will be to the last below the surface of the liquid. The height to which a liquid can be raised by a siphon depends on the specific gravity of the liquid. The pressure of the air supports a column of water nearly 10^m high; hence the highest point of a siphon used for transferring water must not be more than 10^m above the surface of the water. A longer siphon could not be filled by suction, and if filled by other means it would not act, for when the instrument is inverted, the water would immediately leave the highest portion, and fall until in both branches the column had a height of 10^m only; this is shown in fig. 172. Water may thus be

conducted by a siphon over an elevation less than 10^m , as for example a dyke, or a wall, but not over a mountain. In the same manner, a siphon used for transferring mercury must be somewhat less in height than the column of mercury which is supported by the atmospheric pressure, that is, less than 76^{cm} .

A siphon may be kept filled with liquid, if both branches are precisely of equal length, for the pressures at both ends are in this case equal and act in opposite directions. But if the siphon be ever so slightly inclined, as in fig. 173 *A*, the downward pressure of the liquid at *a* becomes less than that at *b*, be-

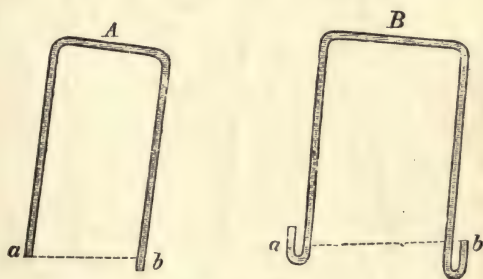


FIG. 173.

cause *b* is below *a*, and since the upward pressure of the air at *a* is now greater than at *b*, the air ascends at *a* while the liquid runs out at *b*. The air enters slowly at first, but gradually more rapidly, because the difference

FIG. 172
 $\frac{1}{100}$ real size).

of the pressures at both ends evidently becomes greater the more the water recedes in *a*, in consequence of its running out at *b*. But if the siphon has the form shown at *B*, and it be inclined, some liquid will run

out at *b*, but the surface of the liquid at *a* is not raised thereby: it descends and remains at the same height as that at *b*. Such a siphon (usually called a 'Württemberg siphon') may therefore be kept filled ready for use; if one end is dipped into the liquid, the latter will immediately run out at the other end.

The siphon being usually filled by dipping one end into the liquid and sucking at the other, another form of it, represented in fig. 174 *A*, is used for liquids

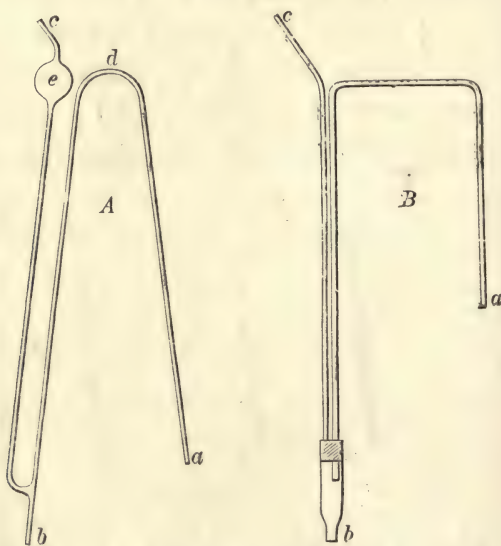


FIG. 174 ($\frac{1}{4}$ real size).

the presence of which in the mouth would be objectionable. The end *a* is dipped into the liquid, the end *c* is closed by the finger, and the siphon is filled by sucking at *c*; when both branches, *ad* and *bd*, are full, the finger is withdrawn and the liquid runs out at *b*. An enlargement *e* renders the passage of any liquid into the mouth still more difficult.

Fig. 174 *B* is a siphon for objectionable liquids, which may be put together by means of three tubes, one being wide enough to admit a small cork through which the other two are passed; the cork should be fixed with sealing-wax. The lower end *b* of the wider tube should, if possible, be made more narrow by drawing it out; a piece of india-rubber tubing may then be attached to it when such liquids are to be transferred as sulphuric acid, etc., the contact of which with the finger should be avoided; *b* is then closed, as long as required, by pressing the india-rubber tube between two fingers.

A simple piece of india-rubber tubing is often used as a convenient form of siphon, since it may be bent into any desired shape; the walls of the tube should, however, not be too thin, otherwise it easily forms a sharp angle at the bend, and its upper portion is liable to be compressed by the atmospheric pressure which at the higher points of a siphon always exceeds the pressure of the liquid.

The applications of the siphon are extremely numerous. Fig. 175 shows a fountain, which is easily constructed by bending a glass tube, one end of which is drawn out into a fine point, four times at right angles, and dipping the other end in water; when the tube is filled it acts like a siphon.

For many physical experiments a constant and steady supply of water is required. Fig. 176 shows a reservoir easily constructed for this purpose by means of glass tubing and a capacious earthenware pot, which may be placed upon some tall piece of furniture or on a proper bracket. The tube *aa* is a siphon; over the outer end an india-rubber tube, a few metres long, is drawn, and firmly tied with thread, while the other end is closed by a stout pinch-cock, or, better still, by a brass stop cock, one end of which can be inserted into the india-rubber tube. The tube *bb* is an *indicator*, which shows the height of the water in the reservoir. It is a siphon one branch of which is bent upwards; the surface of the water is therefore at

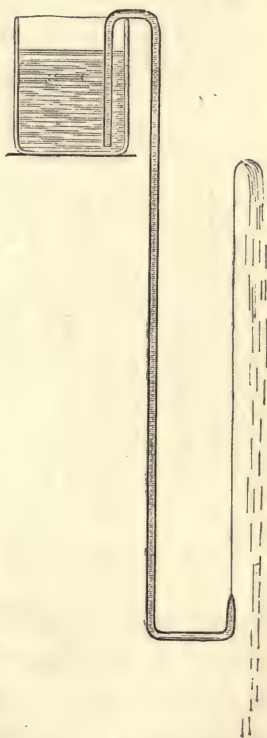


FIG. 175 ($\frac{1}{2}$ real size).

the same level inside and outside, provided that in filling the tube by suction no air-bubbles are left in its upper portion. A small cylindrical float of stearine, which must be narrow enough to move up and down the tube without friction, shows the height of the water in the reservoir more distinctly; if the wall of the room is dark, the float may be left white; but if the wall is of a light colour, the float should be blackened by rubbing it over with powdered graphite (black-lead).

The action of the *pipette*, of which we have made use on a previous occasion (fig. 11), and of the 'wine-taster,' fig. 177, used in the wine trade for removing small quantities of wine from casks, depends upon atmospheric pressure. If the lower end of a pipette is dipped into a liquid, the effect of suction at the

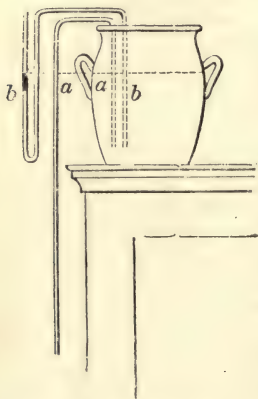


FIG. 176 ($\frac{1}{25}$ real size).

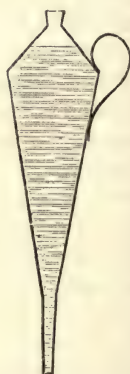


FIG. 177 ($\frac{1}{10}$ real size).

upper end is to diminish the pressure within; the liquid is therefore pressed upwards by the excess of the external over the internal pressure, it rises in the pipette and cannot flow back again if the upper end is closed by the finger, and the air is thus prevented from entering. The pipette may also be filled by simply dipping it into the liquid without closing the

upper end; when full, the upper end is closed and the pipette withdrawn; but the liquid will not run out, for the air which may have remained above the liquid, though it has at first the same pressure as the air outside, expands and allows a small portion of the liquid to escape: its pressure thus diminishes until the excess of the external pressure of the air over the internal is equal to the pressure of the liquid in the pipette.

By means of a pipette with a somewhat capacious bulb, so that the volume of the enclosed air is not too small, it may be shown that the air inside expands in consequence of the pressure of the external air being partially neutralised by the pressure of the liquid in the

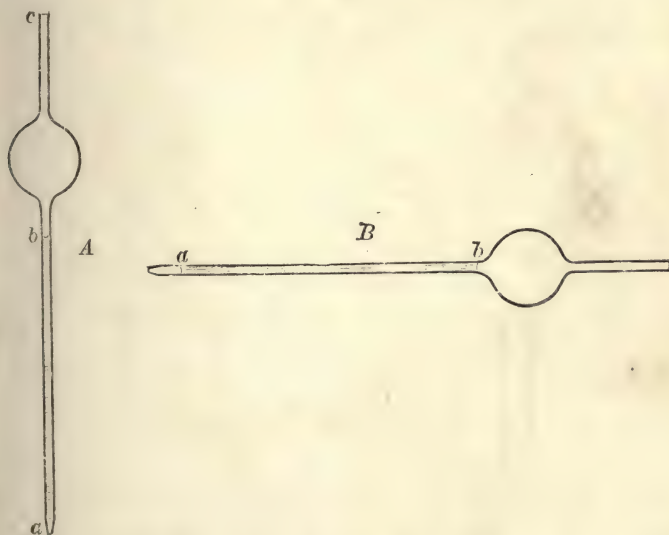


FIG. 178 ($\frac{1}{5}$ real size).

pipette which acts in an opposite direction. Thus suppose that, after partly filling the pipette, the water has been allowed to run out until a column of 20^{cm} remains behind, as shown in fig. 178 A. At the pressure of the atmosphere is equal to a column of water 10^m

high, and as this pressure decreases upwards, it amounts at b to $10^m - 20^{cm} = 9^m \cdot 8$ only, and as there is equilibrium, the pressure of the enclosed air is also equal to that of a column of water $9^m \cdot 8$ high. Let the pipette now be held in a horizontal position without removing the finger from c , and suppose the volume of the enclosed air to be 50^{cc} . In the horizontal position of the pipette, fig. 178 B , both ends of the column of water must evidently be under equal pressures if there is to be equilibrium; but the pressure at the outer end is 10^m , while that at the inner is only $9^m \cdot 8$; hence the column moves, as shown in the figure, and the volume of the enclosed air contracts, until the pressure inside is the same as outside. By Mariotte's law, if the pressure increases from $9 \cdot 8$ to 10 , the volume is diminished in the inverse proportion, hence the volume of the enclosed air is only 49^{cc} , for $10 : 9 \cdot 8 :: 50 : 49$. The column of water consequently moves towards the bulb, and the diminution of the volume of the enclosed air by 1^{cc} will be distinctly observed at a , as shown in fig. 178 B . If the pipette is held vertical, the air will again expand, and the water will move to the end of the instrument.

In this experiment the pipette must be supported by holding the tube, and not the bulb, between the fingers; otherwise the air in

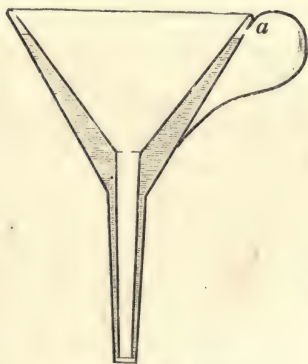


FIG. 179 ($\frac{1}{3}$ real size).

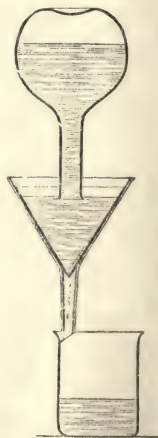


FIG. 180 ($\frac{1}{8}$ real size).

the bulb will expand by the warmth of the hand, and the result of the experiment will be very different.

A well-known toy, the magic funnel, of which fig. 179 gives a section, acts on the same principle. Two funnels of metal are placed one inside the other and soldered together at the upper rim; the tube of the larger funnel projects 1^{mm} or 2^{mm} beyond the smaller, and

below the handle there is a small aperture a . When liquid is poured into the funnel while the lower aperture is closed by the finger, it ascends into the space between the two funnels because this space communicates with the inner funnel by the open aperture of the latter. When the funnel is full, the finger which closes the lower end is withdrawn but the aperture a is closed, which may be done without being perceived by a finger of the hand which holds the funnel; the funnel will then apparently empty itself, while really a quantity of liquid remains behind as long as a is kept closed.

If the lower aperture of a pipette is very wide, it is impossible to retain the liquid in it, because in that case the air and the water have sufficient space to pass each other; but if the aperture be dipped in water, no air can enter, and hence no liquid escapes. Similarly when a vessel which is filled with liquid is turned upside down and its mouth is immersed in an additional quantity of liquid, the vessel remains full, the liquid being kept in it by the external pressure of the atmosphere.

This principle may be applied when it is desired to fill a small vessel repeatedly with liquid from a larger one, and to save the trouble of constantly attending to it, as for example when a liquid has to be filtered in order to remove substances suspended in it. The bottle containing the liquid is inverted, its mouth being closed with the finger or a circular piece of stiff paper, and clamped in the retort stand so that the mouth of the bottle dips a few millimetres into the filter. When the finger or the paper is removed the liquid flows into the filter until the mouth of the bottle is immersed; the flow then ceases, but whenever so much liquid has passed through the filter as to make the surface sink lower than the mouth of the bottle, air ascends in the latter, and fresh liquid flows out. Fig. 180 shows such an arrangement without the necessary supports for the bottle and the funnel.

A plain filter is made from a circular piece of blotting paper, which is folded into halves and then into quarters; it is then opened out, leaving three thicknesses on one side and one thickness on the other, so as to form a smooth cone, which is carefully fitted into a funnel in such a manner as to be well supported all round.

Mariotte's Bottle, fig. 181 *A*, is a bottle with a tubulure *a* for the insertion of the discharge-tube *b*; the neck of the bottle is closed by a tightly-fitting cork, through which the tube *cd* passes air-tight, but so that it may be moved up or down without difficulty. When the lower end *d* of this tube is higher than the mouth of the discharge-tube *b*, as is represented in the figure, liquid flows from *b* while air enters through *cd*. At *d* the liquid is in contact with the external air and the pressure at that point is equal to the atmospheric pressure; from *d* upwards the pressure evidently decreases, but downwards it in-

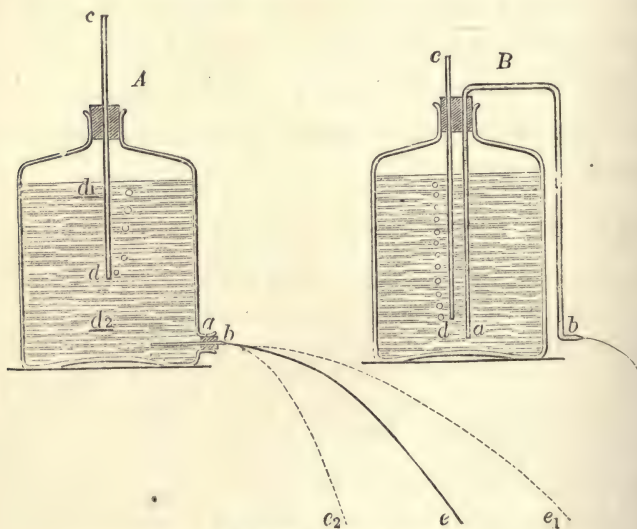


FIG. 181 ($\frac{1}{12}$ real size).

creases, and at *b* it exceeds the external pressure by the pressure of a liquid column which has the height *db*. The difference of pressure, which causes the flow of the liquid from *b*, is thus independent of the real height of the liquid in the bottle; it is the same as if the

surface of the liquid were at d , and it remains constant as long as d and b maintain their relative distance. Hence while the rate at which a liquid flows from a common vessel is continually decreasing, it remains uniform in a Mariotte's bottle until the surface of the liquid sinks below d ; and by moving the tube up or down the rate may be regulated at will. In the figure 181 A , $b e$ represents the form of the jet which issues from b , if the end of the tube $c d$ is at d ; if the end were at d_1 , the jet would have the form $b e_1$, and if the tube were pushed down to d_2 , the velocity of efflux would be considerably diminished, and the issuing jet would have the form $b e_2$. Finally when d is at the same height as b , the pressure is equal at both points, and the flow ceases.

A common bottle may be converted into a Mariotte's bottle by boring a lateral orifice in the manner explained on p. 41, or, as shown in fig. 181 B , a siphon may be passed through the neck of the bottle and used as a discharge-tube.

If air and water are in contact in a confined space, as is the case in Mariotte's bottle, and the surface of the liquid is higher than the point where it is in contact with the external air, the efflux of the liquid will evidently afford more room for the air, the latter will expand, and the increase of its volume will diminish the pressure. It follows that the excess of the atmospheric pressure over that of the confined air constitutes a force which may be employed for driving water or air into the enclosed space. A capacious bottle, fig. 182, is tightly closed by a cork through which pass two tubes; one is somewhat long and straight, the other is bent twice at right angles and

the end which is within the bottle is drawn out into a point. The bottle being inverted, the neck is clamped in the retort-stand and the open end of the bent tube dipped into a glass of water, as shown in the figure. The mouth is next applied to the end of the straight tube, and when the air in the bottle has become sufficiently rarefied by suction, water will be thrown into the bottle as a fine jet, and will run out again through the

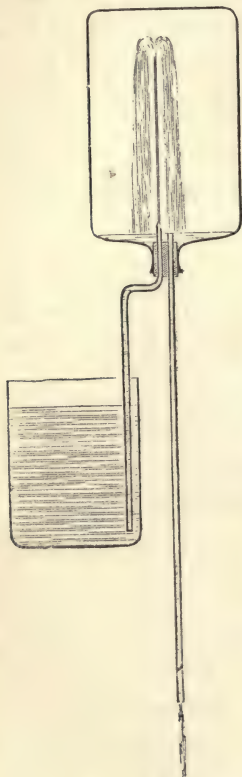


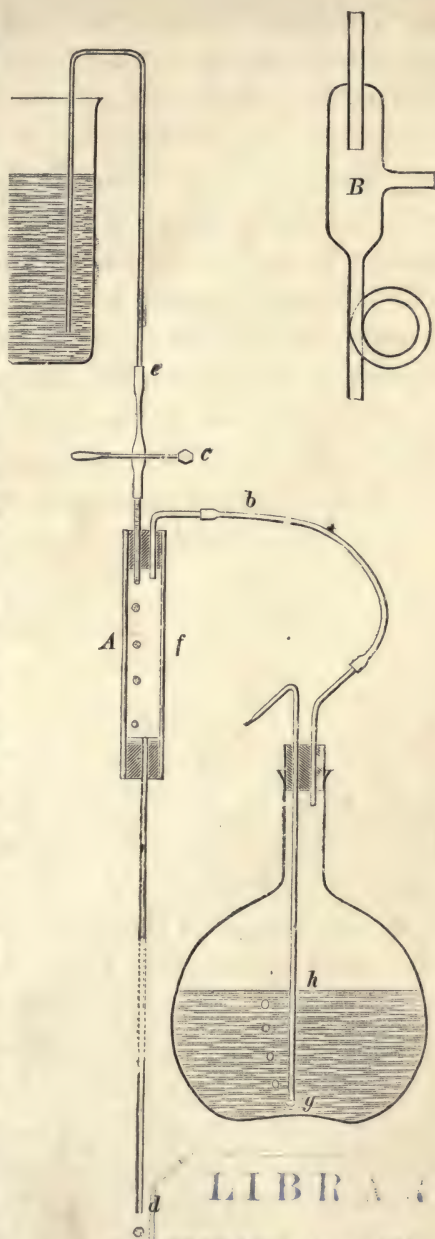
FIG. 182 ($\frac{1}{2}$ real size).

straight tube. Full atmospheric pressure acts on the surface of the water in the glass and at the lower end of the straight tube. At the upper end of both tubes this pressure is diminished by that of the columns of water in them, but since the perpendicular height of the straight tube is greater than that of the other, the pressure at the upper extremity of the bent tube is somewhat greater than that at the upper end of the straight tube. Now, the pressure of the enclosed air, which is in contact with two liquid surfaces under different pressure, can evidently not be equal either to one or to the other: it will be intermediate between both pressures, that is, it will be less than that at the upper end of the bent tube, hence water will be

thrown upwards by the latter; and its pressure will be greater than that at the upper end of the

straight tube, hence through this tube water will flow outwards.

If the water is to rise in a strong jet, the bore of the straight tube should be much wider than the aperture at the pointed end of the bent tube; for in that case the pressure of the enclosed air approaches more nearly to that at the upper end of the straight tube than to that at the pointed end, that is, it is considerably less than that at the smaller orifice, and hence the water is thrown upwards with considerable force. It may happen that too much air has been sucked out of the bottle, and in that case the water which issues from the pointed end will not pass out through the straight tube but will be driven back by the external pressure of the air. This may be avoided by closing the lower end of the straight tube with the finger before it is taken from the mouth; when the jet ceases, the finger is withdrawn and the water issues again, the jet being now higher than before. From time to time water should be added in the open vessel in order to maintain it at a pretty uniform height.



LIBRARY
UNIVERSITY OF
CALIFORNIA.

FIG. 183.

On the same principle air may be driven by the external atmospheric pressure into an enclosed space in which the pressure of the air is diminished by its expansion. Contrivances for producing currents of air are often called *aspirators*. In fig. 183 *A*, a short piece of a wide glass tube, *f*, is closed at both ends by corks, which may be fixed by sealing wax. One cork is bored with two holes, the other with one, and glass-tubes, having respectively the form shown in the figure, pass through the holes; the lower tube should be from 40 to 80^{cm} long. Both tubes are connected at the upper end with short pieces of india-rubber tubing, one of which may be closed by a screw pinch-cock, fig. 184; in this manner

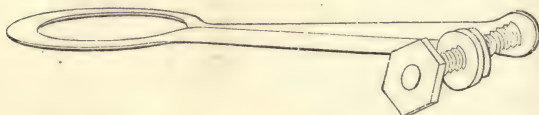


FIG. 184 (*an. proj. real size*).

the quantity of water which flows through the tube may be regulated at will. The upper end of this india-rubber tube is connected with a siphon, or, by means of a glass-tube, with the reservoir described previously. The other india-rubber tube, through which the air enters into *f*, is connected with the vessel through which a constant current of air is desired; in the figure it is connected with a washing bottle, and this may be done in every case, when the mere fact is to be demonstrated that a current of air flows through the apparatus. The pinch-cock *c* being opened, water is allowed to flow through *f* until it passes out at *d*; if

e is not connected with a reservoir but with a siphon, then b must be closed with the fingers and the mouth applied at d , until water has been sucked through the apparatus and flows out at d . It is evident that as long as the same quantity of water flows out at d as that which passes through c , no alteration takes place in the volume of the air enclosed in f , and hence no alteration in the pressure of the air, and nothing will happen when b is opened. But if now the passage in the tube e be made narrower by turning the screw of the pinch-cock, more water will flow out at d than can enter the space f from above, the air in f will therefore expand, and its pressure will diminish, until the pressure of the external air exceeds it sufficiently to cause a current of air to enter the open end of the tube g , to overcome the resistance of the column of water gh , and to flow into the space f , whence it is carried away again by the water through d .

If a weak current of air is required, the water should pass through e merely in drops; but as in that case the water is likely to flow down on the sides of the space f without sweeping any air out of it, the tube should have a loop below f , and close to it, as shown in fig. 183 *B*. The loop collects the descending drops until they fill the section of the tube, the water that has accumulated then flows out all at once and pushes a certain quantity of air before it.

The screw pinch-cock, fig. 184, is made of a piece of stout brass wire, 16 or 18^{cm} long, one end of which is hammered flat, and flattened in the spirit-lamp; a hollow (not a hole) is then punched in it for the reception of the end of the screw. The other end of the wire is formed into a ring, about 4^{mm} wide, upon which is soldered a round flat piece of brass, 8 or 10^{mm} wide and 2 or 3^{mm} thick. This piece has a hole drilled in the middle and is tapped to fit a screw which has the finest thread that can be cut with the screw-stock; the wire is next bent into the proper form and hammered flat and elastic; to prevent its becoming soft by

the heating of one end, or when the piece is soldered on, it is advisable to wrap a piece of wet rag round the portion not to be heated. The screw is made of a stout piece of brass wire, 4mm thick, which is soldered at one end into a knob of thick sheet brass (made six- or eight-sided by filing) after the screw has been cut upon it, or otherwise the wire is apt to be broken off the knob again while the screw is cut. The little piece which forms the knob is also tapped, the screw is left a little longer than required, screwed into the knob, a small piece of solder is laid on carefully to prevent its running down upon the threads of the screw, and finally the portion of the screw which projects on one side beyond the flat knob is nipped off, and filed smooth. A forward motion of the screw opens the pinch-cock, which may thus be adjusted to any required aperture.

Fig. 185 *A* represents a small hollow bulb of glass, open below, which contains air and water in such

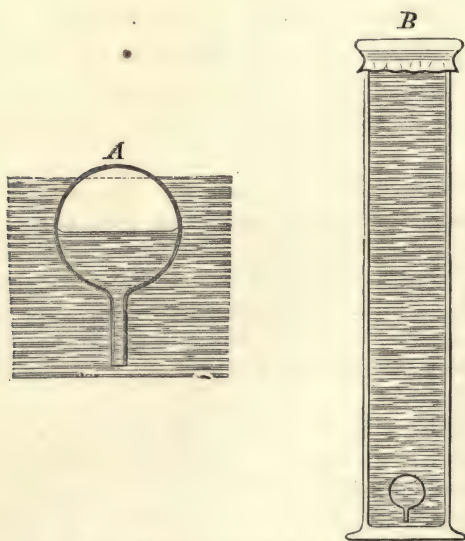


FIG. 185 (*A* real size, *B* $\frac{1}{4}$ real size).

quantities that it floats nearly immersed and that very little more water is required to make it sink. Such a body is usually called a *Cartesian diver*; it is placed

upon the surface of water in a tall cylindrical vessel *B*, over the mouth of which first a soft piece of bladder and then a piece of cloth or other fabric is tightly stretched and tied; the mouth of the cylinder should for this purpose have a projecting rim. If now strong pressure is applied by the hand to the cover, the pressure is transmitted through the water to the air enclosed in the bulb; the volume of the air consequently diminishes, and a small quantity of water penetrates into the diver, which becomes thereby heavier and sinks. When the pressure is relieved, the air in the bulb expands, expels the excess of water which had entered it, and the diver being now lighter, rises to the surface. Usually the 'diver' is a small figure of glass or porcelain, either attached to a bulb, or being hollow, and partially filled with air and water, acts precisely upon the same principle as the bulb alone.

The bulb may be filled by heating it over the spirit-lamp and dipping the aperture in water; the glass being very thin it bears rapid cooling without cracking. The air within, when heated, expands and a portion escapes; the remainder contracts when again cooled in the water and the latter enters to replace the air which has escaped. If a sufficient quantity of water did not enter the bulb after the first heating, it is again held over the spirit-lamp, the heat now being applied to the space above the water already in the bulb; otherwise the water is heated and escapes, but not the air; again, if too much water is in the bulb, a portion may be removed by sucking or by heating it.

When the diver is at the bottom of the cylinder, the enclosed air bears not only the pressure of the hand applied to the cover, but also that of the column of liquid which is above it; hence when the pressure of the hand is removed while the diver is at the bottom

the enclosed air is still under a greater pressure than originally, and the volume of the air does not recover its original magnitude until the diver has again ascended to the surface. It follows from this, that if the apparatus is of considerable size, and the relative quantities of air and water have been well adjusted, the pressure of the column of water above it may be sufficient to keep the diver at the bottom when it has once descended. It must then be raised again to the surface by some means, for example by a hook of wire, and will float when raised; by pressure it will again sink, and remain at the bottom, until lifted again, and so on.

A diver of this kind may be made of a medicine bottle, about 4^{cm} wide and 8^{cm} high. The volume of the enclosed air must necessarily be large, so that a small increase of pressure produces a comparatively great diminution of volume. The bottle is therefore made to float nearly immersed by winding thick lead wire round its neck, which also keeps it in an upright position, its mouth downwards.

In fig 186 *A*, a body *cdef* floats in the liquid contained in a vessel which is not much larger than the body. The weight of the displaced liquid must hence be equal to the weight of the body, or, in other words, the pressure of the liquid upon the surface *ef* balances the weight of the body. But this does not strictly represent the whole of the circumstances of the case; for the atmosphere exerts also a definite amount of pressure upon the floating body and upon the narrow surface *ab* of the liquid which surrounds the body like a ring. The pressure of the atmosphere upon the sides of the body acts in a contrary direction at every pair of opposite points, and no effect is produced; but the

pressure upon cd would tend to push the body down into the liquid, unless counteracted by an equal and opposite pressure. Now, the pressure of the atmosphere acts also upon the liquid surface ab , it is transmitted in the liquid and increases downwards by the additional weight of a liquid column: at ef the pressure is greater than that of the atmosphere at cd by the weight of a liquid column which has ef for its base and the depth of ef below ab for its height, that is, the pressure at ef exceeds that at cd by the weight of the floating body. Suppose next the whole to be inverted, without any displacement, as in fig. 86 *B*. In this position we have still at cd and

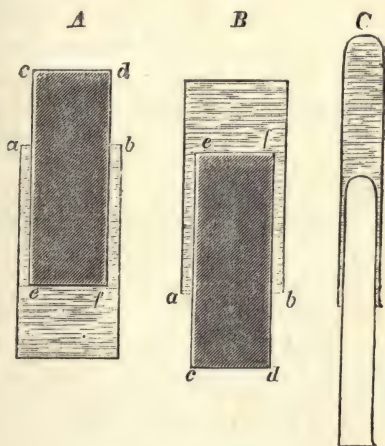


FIG. 186 ($\frac{1}{3}$ real size).

at ab the pressure of the atmosphere, but ef is now higher than ab , and since the pressure now decreases from ab towards ef , the pressure upon ef is now less than upon cd by the same amount as that by which it was previously greater; that is, the pressure upon cd

exceeds that at ef by the weight of the immersed body, and this excess will keep the body floating when the vessel is inverted. If the body $cdef$ be now pushed somewhat upwards and deeper into the liquid so that some of the latter escapes, the surface ef will be still higher above ab than before, the pressure upon ef becomes still less while that upon ab remains the same; the difference of the two pressures is now greater than the weight of the body, and the latter moves upwards in the inverted vessel while the liquid is forced out.

For this interesting experiment two test-tubes are required, one wider than the other. The smaller one should be about 1^{cm} wide and fit rather closely in the larger, but should be capable of moving in it without friction; the space between them should be very little more than 2^{mm}, that is, the external width of the smaller test-tube should be about 0^{cm}·5 less than the internal width of the larger. Fill the larger test-tube with water; hold it upright, place the smaller inside, and wait until it sinks no longer; the escape of the water may be facilitated by loosely placing a finger upon the rim of the larger test-tube. When the whole is in equilibrium, invert it rapidly, by pressing the thumb and the forefinger of the right hand at opposite sides upon the rim of the larger and the side of the smaller test-tube; if slowly inverted, the water is apt to run out. Hold the upper end of the whole in the position fig. 186 C with the left hand, remove the right, and the smaller test-tube will remain at rest; push it with the finger a few millimetres up into the larger tube, and it will continue to ascend if the finger is withdrawn, at first slowly, but more rapidly as the difference in height between the rim of the larger tube and the curved end of the smaller, which respectively correspond to ab and ef , increases.

28. *The Air-pump. Experiments with the Air-pump.*—Many experiments on the pressure and the expansive force of air are made with the *air-pump*, of which a simple form is represented in fig. 187. A tube of metal cc , fig. 187, A and B , with stout walls the interior of which is bored with great accuracy so

as to form a smooth hollow cylinder of exact form, is attached to two supports which are fixed upon a flat board. In the cylinder (often called the *barrel* of the

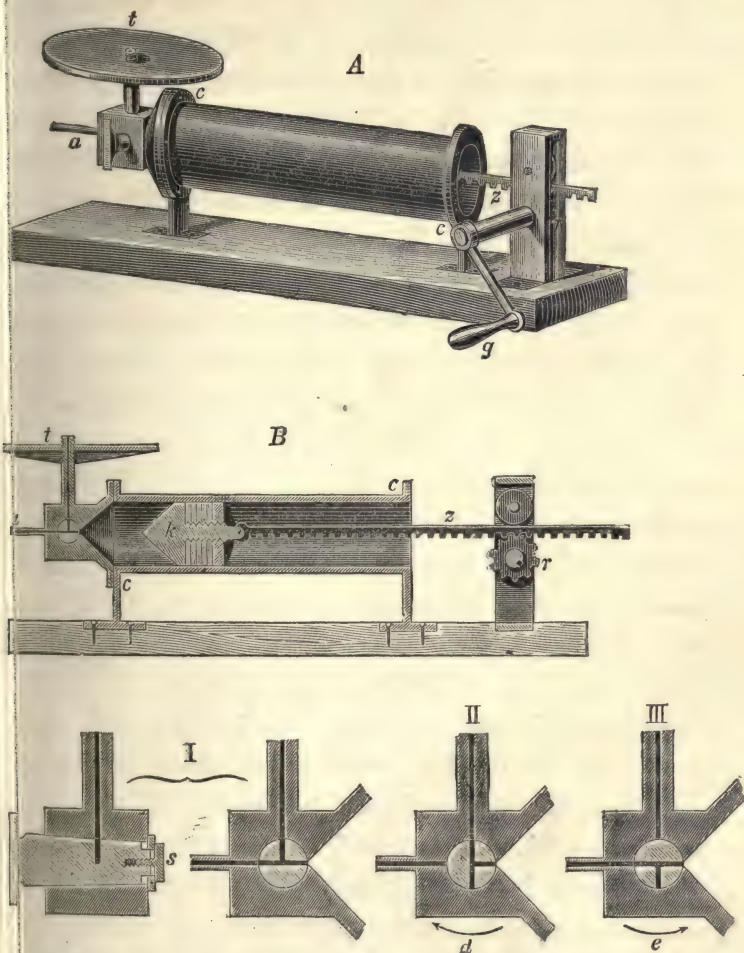


FIG. 187 (A, an. proj., $\frac{1}{6}$ real size; B, $\frac{1}{6}$ real size; I. II. III. $\frac{1}{3}$ real size).

r-pump) the *piston* *k* works air-tight; it consists of a conical piece of metal from which a strong screw projects, which fits into a nut, bored in a disc of metal.

Several discs of well greased leather are placed one upon another, between the flat side of the conical piece and the nut ; by screwing the nut down upon them, they are pressed firmly together, and at the same time they are squeezed out sideways, so as to fit close against the sides of the cylinder and prevent the passage of air. The piston is moved by a handle *g*, by means of a rack *z*, and a cogwheel *r*, while a small cylinder above the rack keeps the teeth of the latter in contact with those of the wheel. The barrel is closed at one end by a solid piece which is attached to it by six screws; the joint being made air-tight by a greased leather washer. The solid piece contains a conical cavity into which the end of the piston exactly fits; close to the pointed end of the cavity there is a stop-cock, which is shown on a larger scale at I, II, and III. This stop-cock is perforated by two channels, one of which passes right through it as in a common stop-cock, the other is perpendicular to the first and passes from the side to the middle only, so that both together form the figure of the letter **T**. Opposite to the pointed end of the conical cavity is a small tube *a* which opens freely into the air; another tube with stout walls rises upwards from the stop-cock, and to the end of this tube a plate of metal, *t*, is screwed, which is either carefully ground flat or has a flat plate of glass attached to it. The screw which bears the plate projects a little beyond it, and various pieces of apparatus may be attached to it, when required. The vessel from which the air is to be exhausted is usually called the *receiver*. It is either provided with a neck which corresponds to

the projecting part of the screw, or it has a wide opening, the edge of which is ground flat, and when greased with lard and placed upon the plate, closes air-tight. The receivers used for most experiments are wide-mouthed glass vessels with stout walls. The whole air-pump is fixed to the table by a strong screw-clamp.

Suppose now that a receiver has been placed upon the plate, and is to be exhausted. First, the stop-cock is placed in the position I.; the receiver is now connected with the barrel, and by means of the tube *a* with the external air. The handle is then turned so as to move the piston to the extremity of the barrel, as far as it can possibly go, so that no air may be left in the barrel between the piston and the stop-cock, which is now brought into position II., which stops the communication of the receiver and barrel with the external air, but not between the receiver and the barrel. If now the handle is turned in the opposite direction, the piston moves away from the stop-cock, and leaves an empty space, which, however, is immediately filled, because the air in the receiver expands; and if the volume of the barrel were equal to that of the receiver, the air in the latter would expand to double its previous volume, while its density would decrease by one half. If the volume of the barrel were greater than that of the receiver, the increase in volume and the consequent diminution of density would be proportionally greater; on the other hand, if the receiver is greater than the barrel, the increase in volume and diminution of density are less. When the piston has reached the end of the cylinder, the stop-cock is

brought into position III., by turning it in the direction of the arrow *d*. The receiver is thereby shut, while the barrel communicates with the external air by the tube *a*, and since the air in the barrel is rarefied, the external air rushes into it with an audible sound, until the air inside and outside the cylinder has the same density. The air is now again removed from the cylinder by working the handle until the piston is at the opposite end—at the bottom—of the cylinder; the stop-cock is, by a turn in the direction of the arrow *e*, brought back into the position II., and the whole operation is repeated. At every withdrawal of the piston the air in the receiver expands so as to fill the barrel as well, and the rarefaction proceeds according to the same proportion at every stroke of the piston as that which was determined at the first stroke by the relative capacity of the receiver and the barrel. Thus, if both have equal capacity, the density of the air in the receiver after the second stroke of the piston is $\frac{1}{4}$ th of its original density, after the third stroke it is reduced to $\frac{1}{8}$ th, after the fourth to $\frac{1}{16}$ th, and so on; for example, after the tenth stroke it will be diminished to $\frac{1}{1024}$ th. If the receiver has only half the capacity of the barrel, the degree of rarefaction after the first stroke is $\frac{1}{3}$ rd, after the second $\frac{1}{9}$ th, and after the seventh it is already as much as $\frac{1}{2187}$ th; if, on the contrary, the receiver is twice as capacious as the barrel, the density of the air in the receiver after the first stroke is reduced to $\frac{2}{3}$ rd, after the second to $\frac{4}{9}$ ths, and after the tenth to no more than $\frac{1024}{59049}$, that is, to nearly $\frac{1}{58}$ th of the original density. It will thus be seen that the exhaustion proceeds the more rapidly, the larger the

air-pump, that is, the larger the barrel, and that the receiver should be selected for every experiment so as not to be more capacious than absolutely necessary.

It would appear from what has been stated, that the exhaustion of a receiver may be continued to an unlimited degree; but in reality this is by no means the case, and a diminution of density to $\frac{1}{1000}$ th is practically almost as much as can be obtained. In order to account for this, it must be remembered that the channels of the stop-cock, while the latter passes from the position III. into position II., are filled with air which has the density of atmospheric air under the usual pressure, and that a definite quantity of such air is mixed every time with the rarefied air in the receiver. As the exhaustion proceeds, the quantity of air removed at each stroke becomes proportionally less and less, and at last the quantity removed will be equal to that which is allowed to enter the receiver from the channels of the stop-cock; from that instant the degree of exhaustion evidently cannot be further increased. The capacity of the channels in the stop-cock is for this reason often called the 'noxious space,' and it is generally further increased by the end of the piston not fitting exactly in the bottom of the cylinder, so that a quantity of air of atmospheric density is left behind in the space between piston and barrel, which at the next turn of the stop-cock enters the receiver. The noxious space should therefore be as small as possible, and a variety of contrivances have been invented to reduce its influence or to avoid it. By means of more complicated machines the exhaustion of

the air can be carried to a very high degree, although in none of them a perfect vacuum is attainable.

An air-pump is a rather expensive apparatus, and the student should prefer to forego the advantage of possessing one rather than purchase a cheap air-pump, which is certain to be useless.

To preserve an air-pump in a good serviceable state, great care is required. Dust should never be allowed to get inside the barrel, for it would spoil it; the pump should therefore always be kept in a closed box, when not in use. In cold weather it should be allowed to stand in the warm room for a time, so as to acquire the warmer temperature; if the piston is moved before, the pump is apt to be damaged. The piston should always be well greased with lard, which must be free from salt; oil makes the whole sticky, and salted lard attacks the metal. The stop-cock should move smoothly, but not too easily; if it is too loose, it may be somewhat tightened by cautiously turning the screw *s* (fig. 187 I.); but if it is too tight, it should be taken out and greased with tallow, care being taken that none of it gets into the bores, and the stop-cock, and the inside of the aperture in which it rests, very cautiously cleaned. Special precautions with reference to particular experiments are given further on. Great care should be taken not to let any mercury get inside the pump, for in that case the whole would have to be taken to pieces, every part thoroughly cleaned, fresh lard put on, and the parts again put together, an operation which is rather difficult to an unpractised hand; the necessity for it should therefore be avoided by proper care.

In a receiver sufficiently tall to allow of a barometer being placed under it, the decrease of pressure manifests itself immediately as the exhaustion proceeds; at every stroke of the piston the mercury descends in the tube. Usually, however, the pressure in the receiver is measured by means of the *siphon-gauge*, that is, a short siphon-barometer, varying in height from 6 to 20^{cm}, which may be conveniently placed under a common receiver. If we suppose a short bent tube with two legs of about equal length, one of which is closed and filled with mercury, while the other is only

partially filled with it, to be placed under the receiver of the air-pump, while the atmosphere is still at the common pressure and communicates freely with the open end of the gauge, the pressure of the atmosphere will sustain the mercurial column in the closed branch, which is shorter than a common barometer, and the closed leg of the tube will remain filled; and no change will happen in the height of the mercury in both legs, even after several strokes of the piston, as long as the pressure of the air in the receiver is capable of supporting a column of mercury equal to difference in height between the surface of the mercury in the closed leg, and the surface of it in the open branch. But when the pressure of the air decreases, the weight of this column will predominate, and the mercury in the closed branch will fall, so that the difference of the levels in the two legs will always be equal to the pressure of the rarefied air in the receiver. Thus, if the surface of the mercury in the closed leg is 1^{cm} higher than that it is in the other, the pressure of the air in the receiver is the seventy-sixth part of the common atmospheric pressure. A good air-pump should be capable of diminishing the pressure in the receiver until the gauge indicates only a difference of level of 1^{mm}.

The gauge must be perfectly free from air, or otherwise the pressure of the air contained in the closed leg of the tube may be greater than that of the air in the receiver, in which case the surface of the mercury in the open branch will be higher than in the closed; such a gauge would evidently be quite useless.

Care is necessary in letting the air again into the exhausted receiver, or the mercury in the gauge will strike with much force against the top of the closed leg, and may possibly break it; the stop-cock should therefore only very gradually be brought back again into the position I.

In order to test the air-pump by means of the gauge, the air in the receiver must be freed as much as possible from the aqueous vapour which atmospheric air always contains in variable quantities, and which, from causes which will be explained further on, cannot be completely removed by pumping alone. Sulphuric acid possesses the property of absorbing moisture; a small tumbler or jar is therefore filled with the acid to a height of about 1^{cm} and placed by the side of the gauge under the receiver. The same acid cannot be long used for the purpose of drying, but it must be changed from time to time; it should, however, not be thrown away, but used for the preparation of hydrogen and in the galvanic experiments to be described hereafter.

A good air-pump should be capable of reducing the pressure in the receiver to 1^{mm} and of maintaining this pressure if the pump is allowed to stand for a day, the stop-cock being in the position III. If these two conditions are not fulfilled, then either the stop-cock or the plate are not air-tight. But if these two tests are satisfied, the stop-cock is placed in position II.; the mercury in the gauge will then rise a little, because the air from the noxious space has now entered the receiver; the gauge should, however, in this position remain at a constant height at least for several hours, even if during this time the piston be slowly moved to and fro, without altering the position of the stop-cock. If the gauge should show a rise of pressure, either the connection between the cylinder and the solid piece screwed to it is leaky, or the piston does not work air-tight in the cylinder. An air-pump which is defective in this respect when bought should be at once returned to the maker; but if it should become leaky after having been used for some time, it should be placed for repair in the hands of a skilful and *conscientious* workman.

Since the column of mercury in a barometer falls, when the pressure of the air upon the mercury in the cistern is diminished by rarefaction, it follows that if an open tube be dipped into mercury and the air in the tube be rarefied, the mercury will rise in the tube to a height which is nearly equal to the height of the barometer; it would evidently rise to the exact height of the barometer, if by means of the pump the space

above the mercury in the tube could be rendered a perfect vacuum.

Tubes and vessels with narrow necks may be exhausted by connecting them with the tube *a* and using the tube which passes through the plate for communicating with the external air. In that case the stop-cock will have to be placed in position III. before the piston is drawn back, and in position II. before it is pushed in; that is, the order of turning the stop-cock will be simply the reverse of what it is when a receiver is exhausted. For the present experiment a glass tube, 90^{cm} long and from 2 to 5^{mm} wide, bent at right angles 5^{cm} from one end, and is then connected by a short piece of india-rubber tubing with the tube *a*, the long portion of the tube being allowed to hang straight down by the side of the table. The ends of the tube *a* and of the glass tube must be in close contact within the india-rubber connection, or the portion of the soft india-rubber tube between both ends would be compressed by the external air when the exhaustion inside the tube proceeds, and the proper connection of the parts would be interrupted. The india-rubber tube should be tied by thread round both tubes, if it does not fit perfectly tight. The other end of the tube is dipped into the vessel represented in fig. 162, filled with mercury, and it should be allowed to rest upon the bottom of the vessel, for when partially filled with mercury the tube becomes heavy and exerts too strong a pull at the india-rubber, unless it is supported below. The space to be exhausted is in this experiment very small, and at the first stroke of the piston the rarefaction is already so great as to raise the mercury in the tube to a height of about 70^{cm}. The quantity of mercury contained in the vessel should therefore be sufficient to cover the lower aperture of the immersed tube to the end of the experiment, as otherwise, if it be exposed to the air, the atmospheric pressure forces the column in the tube upwards and throws it violently into the pump. When the experiment is finished, the stop-cock should be very slowly turned into position I., so that the mercury in the tube may sink gradually, and not be thrown beyond the rim of the vessel.

The great force of the atmospheric pressure is shown in a striking manner by the apparatus called the *Magdeburg hemispheres*. It consists of two hollow hemispheres of metal, with evenly ground edges which

fit exactly one upon the other; both are provided with handles, and one with a tube which may be screwed to the projecting tube of the plate, and can be closed by a stop-cock. The edges being smeared with lard, the hemispheres are placed upon one another, screwed to the plate of the air-pump, and exhausted, so that the space between them is rendered a partial vacuum. The external air will then press the two hemispheres together with a force equal to the difference between the pressure of the external air and the pressure of the rarefied air within; the amount of the compressing force may be tested by seizing the handles and attempting to separate the hemispheres, after the stop-cock has been closed and the apparatus unscrewed from the pump. If the diameter of the interior be 5^{cm} , the force required to separate the hemispheres will be about 20^{kg} ; with a diameter of 10^{cm} it is 80^{kg} , and if the diameter is 20^{cm} it will be as much as 300^{kg} , as can be easily calculated by finding the area of the circular section through the middle of the interior, and multiplying the number of square centimetres in this area by the atmospheric pressure upon 1 square centimetre (about 1^{kg}). The pressure of the enclosed air is so small, when the rarefaction is as great as the pump will permit, that it may be neglected in the calculation.

The edges of the hemispheres should not be flat all round, but one of them should be provided with a projecting fillet, which prevents the possibility of lateral sliding. The force applied should not effect an actual separation of the hemispheres, which might be injured by striking against something, and thus spoiled; they may easily be separated, after opening the stop-cock, by turning one upon the other with a moderate force, required to overcome the adhesion, which makes them still hold pretty firmly together after the air is let in.

The pressure of the atmosphere may be manifested without Magdeburg hemispheres by means of a common receiver of glass. After a few strokes of the piston, force will be required to remove the receiver from the plate. In this case also care should be taken not actually to lift the receiver from the plate, otherwise both pump and receiver might be seriously injured. The receiver should never be taken off, unless the air has been previously let in again. Even in that case there remains adhesion enough, especially when the flat edge of the receiver is somewhat wide, to require some exertion for the separation; it should be turned round between both hands until it moves easily upon the plate, and then lifted off.

The pressure of the atmosphere may be rendered sensible without the air-pump in the following manner. Grind the edge of a glass funnel, 4 or 5^{cm} wide, upon a glass plate with emery powder, in the same manner as was done previously with the edges of the vessels for the hydrostatic experiments (page 167); push a short piece of india-rubber tubing over the tube of the funnel and provide it with a pinch-cock. Lard the flat edge of the funnel, place it upon an adhesion-plate, open the pinch-cock, suck strongly at the end of the india-rubber tube, and close the pinch-cock before you have ceased sucking. The pressure inside the funnel is now so much diminished, that a force of from 3 to 10^{kg}r would be required to separate the plate from the funnel. The application of such a force would evidently endanger the plate and the funnel, both being of glass; but by placing the fingers of the left hand round the edge of the plate and seizing the tube of the funnel with the right hand, a considerable pull may be exerted with safety.

A strong hollow cylinder of glass or metal, open at both ends, may be used to show the crushing force of the pressure of the atmosphere. One edge is ground flat, and upon the other end is tied a bladder, previously softened in lukewarm water, then tightly stretched, and fastened by several turns of string. The flat edge is now larded and placed upon the plate of the pump. When the air inside the cylinder is exhausted, the bladder is bent in by the pressure of the external air, and when the rarefaction can be carried

to such an extent that the strength of the bladder is less than this pressure, the bladder bursts with a loud report. This will, however, only happen if the exhaustion is rapid, as is the case when a large air-pump is used; when the rarefaction is slow, the bladder distends without bursting, and allows air to pass through its pores.

The pressure of the air is capable of forcing mercury through the wooden bottom of a vessel, if the pressure at the opposite side is removed. A small basin of walnut-wood, as *a* in fig. 188, is fixed upon the cylinder of a moderator lamp, the other end of the cylinder being ground flat, and placed upon the

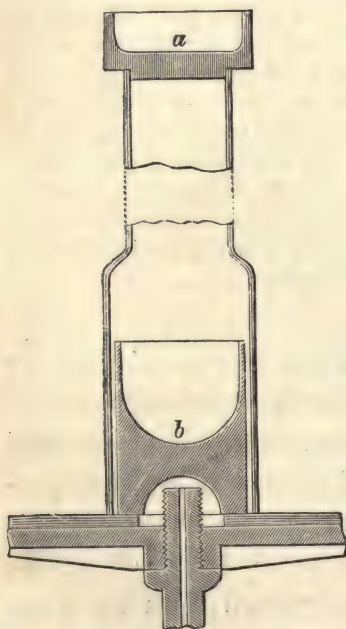


FIG. 188 ($\frac{1}{2}$ real size).

plate of the air-pump. Within the wider portion of the cylinder is placed another little vessel, *b*, made of some dense kind of wood. When the air in the cylinder is rarefied, the pressure of the external air forces fine globules between the fibres forming the bottom of the vessel *a*, and the drops fall in the form of a 'rain of mercury' into the vessel *b*.

The rain must be observed in close proximity; even at a small distance the tiny globules are invisible. The vessel *b*, which prevents the mercury from falling

into the pump, should have a polished surface inside. The small basin *a* should be turned on the lathe in such a manner that the fibres of the wood may be vertical

(as indicated by the lines in the diagram) when it is placed upon the top of the cylinder, into which it may be fixed with sealing-wax.

The fact that air possesses weight may be demonstrated in a more convenient manner than that employed in art. 24, by means of a flask of 1 or 2 litres capacity, provided with a collar of brass and a stop-cock capable of being screwed to the pump. When the flask is exhausted, the stop-cock is closed, the flask removed from the plate, suspended to one arm of the balance, and counterpoised; the stop-cock is now opened very little, so that the air enters but slowly: as the flask is getting filled with air it descends, in consequence of the weight of the latter.

The flask used for the experiment in art. 24 (page 220) may be employed, if the student does not possess a globular flask with brass collar; but for this experiment no water is required. The pinch-cock is first pushed back over the india-rubber until it clamps the glass tube; the tube *a* of the pump is then slightly greased with tallow, and the india-rubber tube is drawn over it until the end of the tube *a* is in contact with the glass tube. After carefully exhausting the flask the flexible tube is cautiously pushed back from *a* until there is a sufficient space between the ends of both tubes to place the pinch-cock between them. When this is done, detach the flask with the flexible tube from the pump, suspend it to the balance, and proceed as before.

The fact that bodies lose weight in air may be demonstrated by means of an apparatus called the *baroscope*, fig. 189. A small pillar supports the beam of a balance; to the opposite ends of the beam two spheres are fixed, one of brass, the other of glass, hollow and air-tight. Both spheres are adjusted so as to be in equilibrium in air. But the volume of air displaced by the sphere of glass is larger than that displaced by the sphere of metal; the glass sphere loses therefore more of its weight than the brass sphere—that

is, the absolute weight of the glass sphere is really greater. The loss of weight caused by the presence of air must cease when the air is removed; hence, when

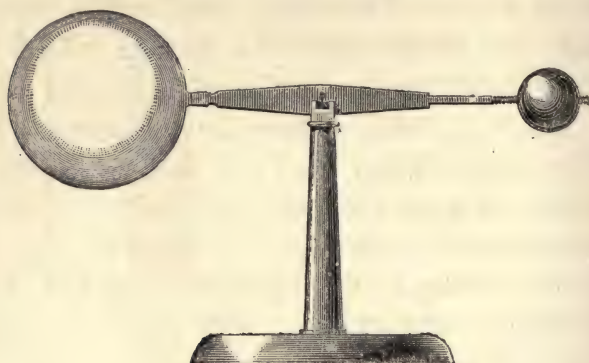


FIG. 189 ($\frac{1}{2}$ real size).

the apparatus is placed under the receiver of an air-pump, and the air is withdrawn, the glass sphere descends; if the air is let in again, the apparent equilibrium is restored.

If the end of the beam which carries the brass sphere forms a screw, so that the brass sphere can be moved further from the fulcrum it is possible to adjust the apparatus so as to be in equilibrium in vacuo, but in air the brass sphere will now descend.

The action of the siphon depends on the pressure of the atmosphere; hence the flow of a liquid through a siphon must cease, if the air is withdrawn. It is difficult to demonstrate this fact, if a light liquid such as water be used; for the pressure of the atmosphere is capable of supporting a column of water 10^m high and the pressure would have to be reduced to one-hundredth in order to stop the flow of water through a siphon 10^{cm} high; before that degree of rarefaction is

obtained the liquid would probably have already passed from one vessel into the other; and besides, the pressure of aqueous vapour, which also exerts some pressure, would interfere with the success of the experiment. Mercury may, however, be used for it. One end of a very narrow siphon, of the form shown in fig. 190, with an aperture in the middle of the lower bend, is

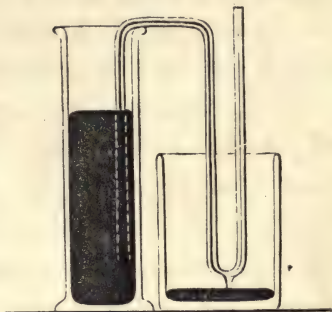


FIG. 190 ($\frac{1}{3}$ real size).

dipped in a cylindrical vessel filled with mercury, which is placed by the side of an empty vessel upon the plate of the air-pump. The mercury is made to flow by sucking, and the whole is then covered by the receiver. The pump being worked, not too slowly, the thread of mercury will first break at the top of the longer branch of the siphon which is outside; but as there is now a vacuum in this branch, the liquid will continue to flow from the vessel through the shorter branch of the siphon which is inside the liquid, until finally, when the pumping is continued, the pressure is insufficient to raise the liquid in the shorter branch to the top of the siphon, and the flow ceases.

The bore of the siphon should not exceed 0^{mm}·5. The aperture at the side is made before the siphon is bent. The tube, 40 or 50^{cm} long, is closed at one end by the finger, and an assistant blows strongly into the tube at the other end. The point of a blowpipe flame is now directed upon the exact place where the aperture is to be made, and that side is heated until it becomes soft, care being taken not to heat the opposite side. A small bulb will be thus formed and then burst. The edges of the aperture are then rounded in a common flame, and the tube bent into the required form.

If the flask used for showing the effect of atmospheric pressure, art. 27, p. 246, be placed under the receiver of the air-pump, a jet will issue from it when the pump is worked, for the pressure of the air upon the water inside the flask is greater than the pressure outside.

The increase of a volume of air caused by decrease of pressure may be demonstrated in various ways by means of an air-pump. A Cartesian diver, made so heavy as to sink, will rise if the vessel which contains it is placed under the receiver, and the air withdrawn. A bladder, only partially filled with air and closed, distends under the receiver of an air-pump; so does a

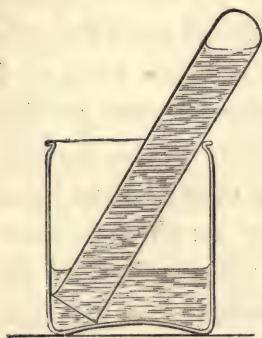


FIG. 191 ($\frac{1}{2}$ real size).

shrivelled apple, because it contains air in the interior. Dense soapsud, placed at the bottom of a tumbler, in a layer about 1^{cm} high, fills the tumbler to the edge, when the air in the receiver is rarefied. A test-tube, nearly filled with water, and inverted in water, as shown in fig. 191, and placed under

the receiver, will become nearly empty when the pump is worked, because the air in the test-tube expands. When air is again admitted into the receiver, the liquid rises in the test-tube to its former height. An egg, through the more pointed end of which a fine aperture is made, will empty itself, if it is placed with the perforated end upon a small tripod made of wire under the receiver; the reason is that the egg contains a quantity of air enclosed at the wider end, which

expands and forces the liquid contents through the orifice.

Water contains always small quantities of air in solution; under the receiver of the air-pump, when the rarefaction is great, this air separates from the liquid in small bubbles, which collect at the sides of the vessel.

Liquids, like soda-water, which contain some gas (carbonic acid gas) in solution, manifest much stronger effervescence under the receiver of an air-pump, because the gas escapes under a diminished pressure.

The experiment with the Cartesian diver may be made without an air-pump, for it requires only a slight rarefaction, if the volume of water in the diver is so adjusted as to make it just sink. The diver is simply placed in a bottle with water, and the air sucked out by the mouth; or, more conveniently, the bottle is fitted with a cork, a tube is passed through it, bent at right angles, and the mouth applied at the end of the tube.

During the experiments with water and watery liquids, some aqueous vapour always gets into the pump; if the exhaustion is great, the water will even boil, for a reason which will be explained further on. These experiments should therefore follow each other in succession, and the pump may then be dried. This may be done without taking the pump to pieces by placing a shallow saucer full of sulphuric acid and the gauge under the receiver, and exhausting the latter as far as possible; the stop-cock is then brought into the position II., and left for an hour, during which the piston is repeatedly moved to and fro. The water deposited in the walls of the cylinder and in the channels of the stop-cock is hereby made to evaporate, and is absorbed by the acid.

It has been stated in art. 10, p. 59, that all bodies fall with equal velocity in vacuo. This may be demonstrated either by means of a long glass tube, of wide bore, closed at one end with an air-tight cap of brass, and at the other by a brass collar, to which is attached a stop-cock and a nut for fixing the whole upon the plate

of the air-pump; or a similar tube, with a well-ground edge at one end, may be simply placed upon the plate, the other end being provided with a cap of a peculiar construction, shown in fig. 192. Inside this cap there is a small plate *p*, which moves about a hinge *c*. Through a so-called 'stuffing-box' *s*, passes a moveable brass rod carrying a small bracket *a*, which supports the plate *p* until the exhaustion is complete; two objects differing considerably in weight, as for example a coin and a feather (hence the apparatus is often called the 'guinea and feather apparatus'), are placed upon the plate before the experiment commences. As soon as the air is exhausted the bracket *a* is turned into the position indicated by dots, the plate drops, and both bodies fall with equal velocities. The apparatus has the disadvantage

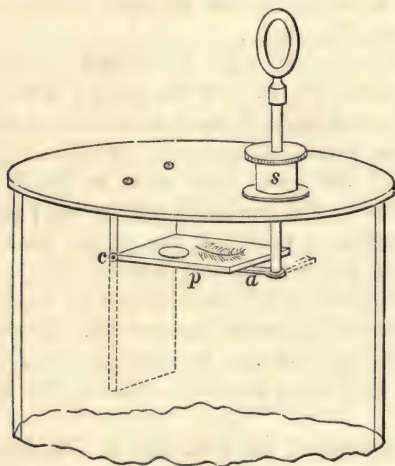


FIG. 192 (*an. proj.* $\frac{1}{2}$ real size).

that it must be taken off the plate, set up again, and exhausted every time that a repetition of the experiment is desired—an operation which is rather tedious, but demonstrates the fact in a very beautiful manner.

If the tube is provided with fixed caps, the falling bodies must evidently be placed inside before the whole is finally closed. Such an apparatus is inverted by the hand in order to let the bodies fall, and the experiment may therefore be repeated as often as desired; but it has the disadvantage that the bodies are apt to slide down along the walls of the tube instead of falling freely.

The disc of lead with steel axis represented in fig. 41, p. 45, will spin about twice as long under the receiver, as in air. It may be set to spin in air, and placed with the watch-glass upon the plate; after covering it over with the receiver, the exhaustion should proceed as rapidly as possible.

The air-pump will be used, further on, in several experiments on heat and electricity.

An air-pump with an exhausting stop-cock may at once be converted into a *condensing pump*. If the stop-cock, while the piston is drawn out, have the position I. (fig. 187), and the position III. when the piston is moved inwards, as if it were intended to exhaust the receiver upon the plate, the air enters from above through *t*), and is ejected through *a*; it follows that if a closed space be connected with the tube *a*, the air in it will be condensed. One end of a piece of good sound india-rubber tubing, about 10^{cm} long, 1^{cm} wide, and the walls having a thickness of 6 or 8^{mm}, is firmly tied round the tube *a* by strong twine; the other end of the tube is closed by winding twine round it and tying it as firmly as possible. By now using the pump as a condenser, the india-rubber tube may be distended to a bag nearly 10^{cm} long, and 3 or 4^{cm} wide, and the walls will become nearly translucent. Bad india-rubber bursts during

the experiment, but good tubing will nearly resume its original dimensions after the air is allowed to escape.

It is not advisable to condense the air under the receiver (which would be done by drawing out the piston

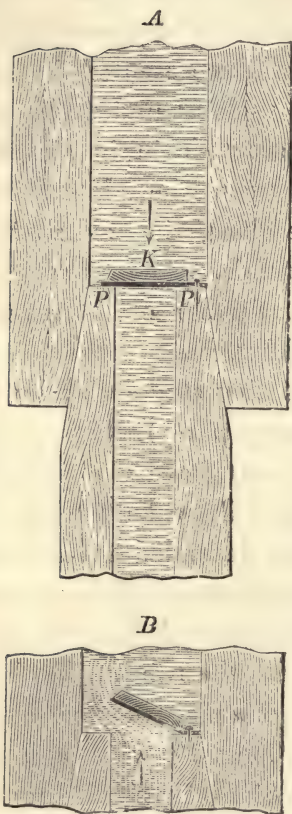


FIG. 193 ($\frac{1}{4}$ real size).

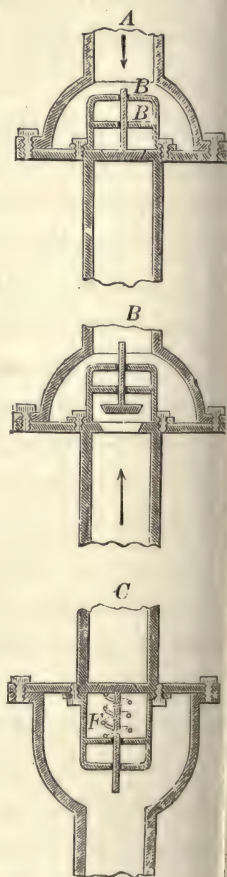


FIG. 194 ($\frac{1}{4}$ real size).

while the stop-cock is in position III., and pushing it (while the stop-cock is in position II.), because glass receivers are liable to burst by the increasing pressure, and to be thrown upwards if they are not well fixed upon the plate; in any case serious accidents may happen.

29. *The Suction-Pump. The Forcing-Pump.*—In the air-pump which has been described, a stop-cock is used for alternately shutting and opening the communication between the receiver, the cylinder, and the external air. In many air-pumps, however, and in all pumps used for water, the stop-cock is replaced by *valves*. A valve may be defined as a contrivance which allows a current of water, or air, or steam, etc., to pass through a tube or aperture in one direction, but not in the other.

One of the most common form of valves is the ‘clack-valve,’ fig. 193. It is usually constructed by attaching to a plate of metal or wood, *K*, larger than the aperture, *PP*, which the valve is intended to stop, a piece of leather, which extends on one side beyond the plate, and being flexible, forms the hinge on which the valve plays. Such a valve is usually closed by its own weight, and is held closed more firmly by the pressure of the fluid whose return it is intended to obstruct (fig. 193 *A*); on the other hand, it is opened by the pressure of the fluid which passes through it, as shown at *B*. Another form is the ‘conical valve,’ fig. 194. It consists of a circular metallic plate with conical sides, resting in a conical seat; in the middle of the valve there is usually a short spindle, which passes through holes made in crossbars, *BB*, and this guides the valve in its perpendicular motion. The action of the conical valve shown at *A* and *B* of the figure corresponds exactly to that of the clack-valve. If the valve is to open downwards, it must be kept pressed against its seat by a spring *F*, shown in fig. 194 *C*.

The *suction-pump*, chiefly used for raising water from wells, is shown in fig. 195. CC is a pipe or barrel

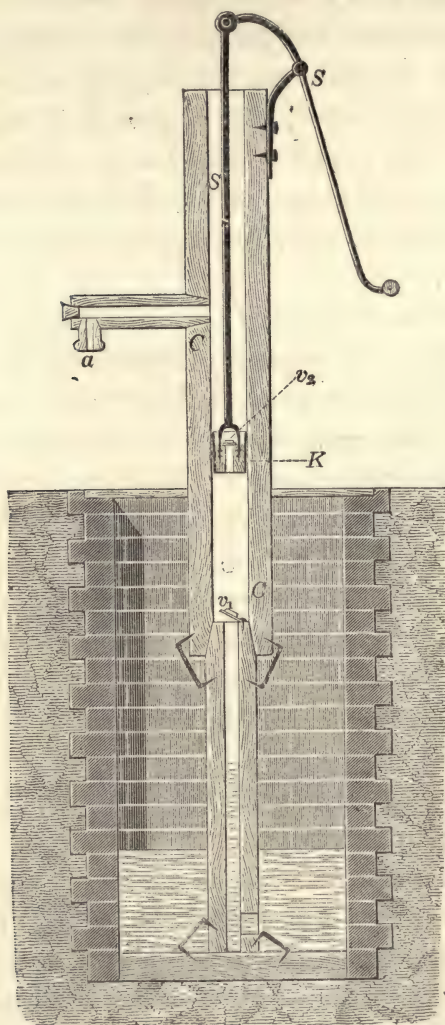


FIG. 195.

with a smooth bore, in which a piston K is raised & lowered by means of the piston-rod S and the be

lever with unequal arms, S , usually called the pump-handle. The lower part of the pipe is formed by a somewhat narrower tube, R , called the suction-pipe. To the top of this pipe a clack-valve v_1 , usually called the *suction-valve*, is attached, represented in the figure as being opened. Another valve, v_2 (the *pressure-valve*), is placed within the piston, which has an aperture for its reception, while the rod is forked at the end so as to afford space for the valve to open. (The relative proportions of the various parts of the figure are not quite correct).

When the piston is raised, the air which fills the space below the piston will expand, and consequently, by Mariotte's law, its pressure will decrease, so as to become less than the atmospheric pressure. No air can enter this space from above, because the valve v_2 opens only upwards: but air enters through the valve v_1 from the suction-pipe, the air in which therefore also expands and has less pressure than the external air which presses upon the surface of the water in which the suction-pipe is immersed. The external pressure thus forces a column of water into the suction-pipe. When the piston descends, the air below it is compressed, but since the valve v_1 is now closed, no air can enter the suction-pipe, and when the pressure of the air enclosed in the space between the two valves becomes greater than that of the external air, the valve v_2 is opened by the excess of pressure, and the air escapes. At each stroke of the piston the described effect is evidently repeated; a portion of the air below the piston is removed, the excess of the external over the internal pressure of the air increases, and the column of water raised by this excess becomes

higher and higher, until after a few strokes of the piston the water rises above the valve v_1 ; after the next downward stroke of the piston it will also rise above the piston itself. No further rarefaction of air can now take place, for when the piston rises, the space below it is immediately filled with water by the external atmospheric pressure; after that, every time the piston is lowered, water from below it passes through the valve in the piston, it is raised when the piston ascends, and flows out through the discharge-tube a .

The length of the suction-pipe cannot exceed a definite limit, for, as has been shown previously, the column of water which can be supported by the pressure of the atmosphere is not more than about 10^m , and water can thus evidently not be raised in the suction pipe to a height greater than 10^m . The valve v_1 must hence be somewhat less than 10^m above the surface of the water in the well, if the water is to be raised above it. In ordinary pumps the suction-pipe must even be shorter, because the piston in such pumps does not work sufficiently air-tight, the rarefaction of the air in the suction-pipe is hence rather imperfect, and the column of water capable of being raised is usually not more than 7 or 8^m .

In ordinary pumps the piston is usually rendered more air-tight by a collar of leather which surrounds the piston like a tube, and is fixed to it below, being somewhat wider at the top. When the piston is raised, the pressure above is greater than that below it, and the collar is pressed closely against the sides of the pipe.

The *forcing-pump*, fig. 196, differs from the suction

pump in having a solid piston without a valve. The air which fills the suction-pipe, and afterwards the water, are removed by means of a tube rr (called the force-pipe), which opens into the barrel above the valve v_1 ; this tube contains the valve v_2 , and both valves, when the piston is worked, act like the two corresponding

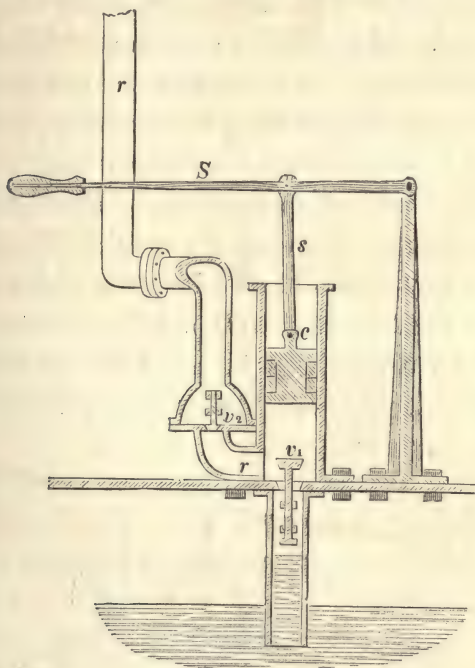


FIG. 196 ($\frac{1}{20}$ real size).

valves in the suction-pump. Thus, when the piston is raised, the air in the suction-pipe expands and opens the valve v_1 ; when the piston descends, the valve v_1 closes, and the air above it is forced by the pressure of the piston through the valve v_2 into the force-pipe. When all the air is thus removed, that is, when the water rises above the valve v_1 , then at each upward

motion of the piston water is drawn from the suction-pipe into the pump-barrel, and at each downward motion it is forced from the pump-barrel into the force-pipe. It is evident that water may thus by adequate pressure be forced to any height to which the force-pipe reaches. Every point of the lever S , by means of which the piston-rod is moved, obviously describes an arc of a circle, of which the fulcrum, which is at one end, is the centre. In order that the rod s may adapt itself to this circular motion, it is attached to the piston by a hinge c , about which it can turn freely.

In many practical applications of the forcing-pump for example in the *fire-engine*, a continued flow of water is produced by means of an *air-vessel*, which acts in the manner of the flask, fig. 169, p. 246.

Fig. 197 (in which, as in fig. 195, the various parts are somewhat out of proportion) gives a sectional

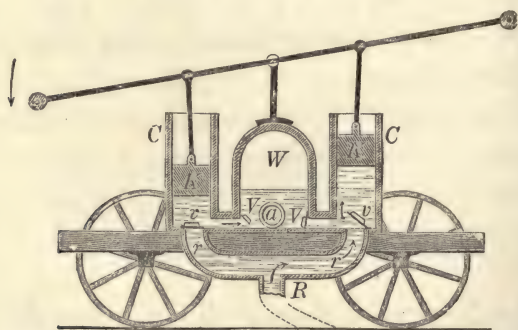


FIG. 197.

diagram of the fire-engine. This is a double forcing pump, each barrel of which acts in the manner explained above, the piston-rods being worked by double lever, so that one piston is raised while the other

is lowered. CC are the two barrels, KK the two pistons, vv the suction-valves, VV the pressure-valves. The two tubes rr join so as to form one suction-tube, R ; the lower end of it is closed by a sieve to prevent the entrance of foreign bodies, as sand, etc., and is dipped below the surface of the water in a reservoir. The two pressure-valves open into the air-vessel W , which has in the side an aperture a , into which a flexible hose may be screwed which ends in a jet-pipe. The solid pistons KK being alternately forced down upon the water which has been drawn into the barrels upon the principles already explained, the water is forced into the air-vessel W , and if the lever is worked with sufficient rapidity, more water will be conveyed into the air-vessel than can be discharged in the same time through the jet-pipe; the air in the vessel W will thus be somewhat compressed, and acts by its elastic force as the air in the flask, fig. 169, that is, a continuous jet is produced which is not interrupted even when the action of the pumps ceases for a short time, as in fact it does for an instant every time the motion of the pistons is reversed.

Fig. 198 A is an easily constructed model of a suction-pump. The cylinder is made of glass tube with strong sides about 15^{cm} long, and so wide that a piece of india-rubber just fits into it; about 14^{mm} is the best width for the bore of the glass tube. A small wooden rod, s , cut neatly round and straight, forms the piston-rod; its diameter at the lower end should be 3^{mm} less than the bore of the india-rubber tube; and the upper part may be somewhat thinner. The handle G is cut out of a thicker piece of wood; it has a hole bored in the middle, is glued to the rod, and for greater safety a wire pin is driven across through the rod and the handle. The piston is made by tying about 15 or 18^{mm} of the india-rubber tube round the end of the rod, as shown at B in the figure; the rubber tube then acts like the leather collar in a common pump;

downward pressure presses it close against the sides of the tube, and nothing is allowed to pass out; while upward pressure separates it from the sides, and allows water and air to pass between; the india-rubber tube thus acts by its elasticity like a valve, and no other valve is required in the piston.

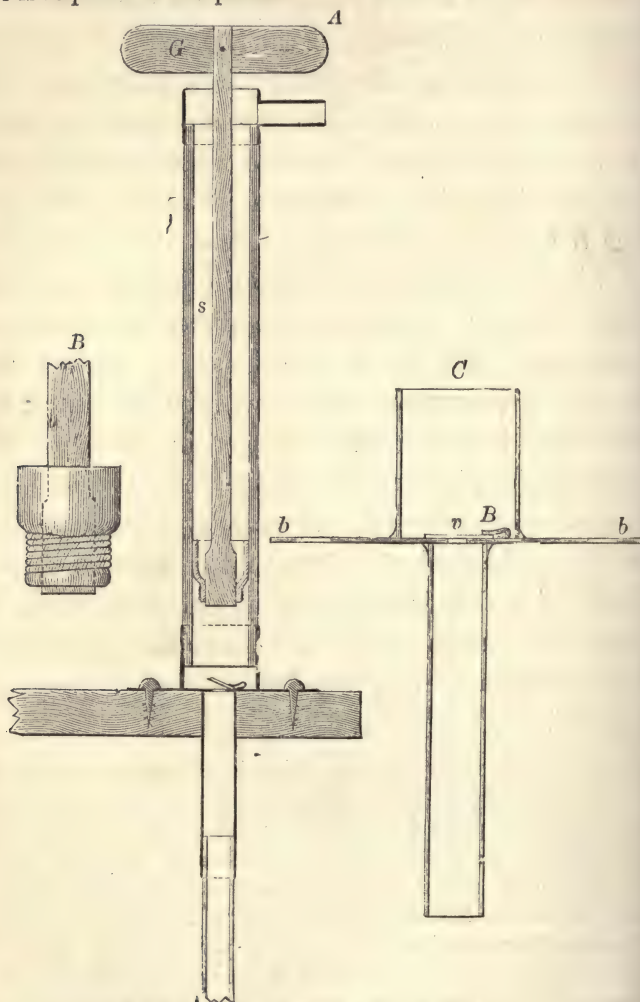


FIG. 198 (*A*, $\frac{1}{2}$ real size; *B* and *C*, real size).

The top of the suction-tube is shown at *C* separately. It consists of a sheet of metal *bb*, to which are fixed two short tubes, one at the upper side, and another, somewhat narrower, at the lower side.

The barrel and the suction-tube are fixed into these pieces; the suction-valve is made of oiled silk.

Cut a circular plate of zinc, 5^{cm} in diameter, and about 0.5 or 0.75^{mm} thick. Punch a hole in the middle, 3^{mm} wide, and also a few holes near the edge, for screwing the plate to a board; the raised edges of the punched poles are hammered flat with the mallet, the middle hole especially being made smooth all round with file and rimer. Take a strip of sheet zinc, 5^{cm} long and 25^{mm} wide, hammer it over a round piece of wood or iron rod into a small tube, and solder one edge upon the other by holding the tube horizontally over the spirit-lamp. File it smooth at both ends, hold the plate horizontally over the spirit-lamp, place the tube with one end upon the middle of the plate, and solder the tube to it. Another strip of zinc, 2^{cm} wide, and three and a half times as long as the external width of the glass-tube, is similarly bent into a tube, soldered along the edges, and by one of its ends to the plate. The narrower tube is for this purpose held by the pincers, the plate uppermost and the wider tube placed upon the upper side of it; to prevent the parts from being displaced while being soldered together, a thin iron wire may be laid across the top of the wider tube, bent down on both sides, and twisted firmly across the lower end of the narrow tube. The small strip of metal by means of which the valve is secured, *B* in fig. 168 *C*, should be soldered to the plate at the same time; it is about 6^{mm} wide, and its form and other dimensions are seen from the figure. The solder should be used sparingly, all joints should be just filled with it, but none must be allowed to run about, or otherwise the interior of the little strip *B* may possibly be filled with it, or drops may spread over the plate, render its surface uneven, and prevent the valve from properly closing. Every trace of soldering fluid should be removed afterwards with water, the water then dried up, and both tubes heated until a bit of sealing-wax melts upon their inner surface. Upon the inner edge of each tube a layer of sealing-wax is spread, about 6 or 8^{mm} wide and 1^{mm} thick, and then allowed to cool. Next fix a piece of yellow transparent oiled silk, *v*, 8^{mm} wide, and 10 or 12^{mm} long, in the manner shown at *C* of fig. 198, by placing one end underneath the bent strip *B*, and then pressing down the strip *B* with some blunt tool until the piece of oiled silk is firmly clamped. The two glass tubes which are to represent the barrel and the suction-tube (the latter of which may be of any length), are then heated and pushed into the metal collars. The latter should not be heated, or the piece of oiled silk would be spoiled; instead of the oiled silk a thin flat piece of india-rubber may be used, such as may be cut out of a broken india-rubber band.

A short metal collar, with a discharge-tube in the side, is now fixed with sealing-wax upon the upper end of the barrel, the aperture for the discharge-tube having been made in the metal before it is bent round to form the collar. The pump is screwed to a small board of wood, which has a hole corresponding to the width of the suction tube, and may be supplied with four legs, so that a vessel of water may be placed underneath, if the suction-tube is short; or the board

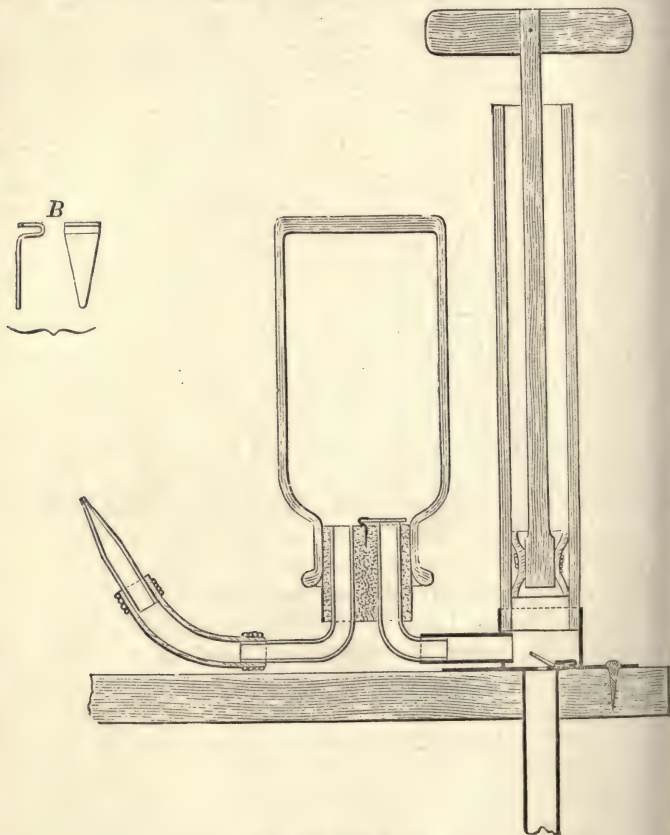


FIG. 199 ($\frac{1}{2}$ real size).

may be fixed by a screw-clamp to the edge of the table so as to project partly, a vessel of water is placed upon the floor, and a suction tube 70 or 80^{cm} long is allowed to dip into the water.

The downward motion of the piston should be rather slow, lest the water forced between the piston and the sides be projected over the top of the barrel; the piston should also be moistened before

being introduced into the glass tube, and be removed again and put aside after having been used; for if allowed to become dry in the tube, the india-rubber adheres too closely to the glass, and cannot be moved afterwards without injury.

A forcing-pump with one barrel and an air-vessel, fig. 199 A, may also be constructed without difficulty. The barrel is again made of a glass tube, and the suction-tube is connected with it in the same manner, the brass collar having, however, in this apparatus, an aperture in the side into which a horizontal tube is fixed, so as to project somewhat inside the wider tube and to fit tightly in the aperture; no wire will then be required for holding it in position while it is soldered. This lateral tube, before the valve is introduced, also receives a lining of sealing-wax at the edge for fixing the glass tube which leads to the air-vessel. The latter is made of a wide-mouthed bottle, such as is used for pomatum, for which a good tight-fitting cork is selected; the cork is bored with two holes. The upper end of the glass tube which connects the air-vessel with the pump-barrel should be carefully ground and melted so that it may have a perfectly flat and smooth edge; it should project above the cork about 0^{mm}·5. The valve, made of oiled silk or india-rubber, is fixed by means of a strip of zinc of the form shown in fig. 199 B, of which the straight portion is stuck into the cork. Another glass tube, bent at right angles, passes also through the cork, and is connected by a piece of india-rubber tubing with a glass tube ending in a fine aperture, through which the jet issues. The india-rubber tube is tied round both glass tubes, or else it might be forced off by the pressure of the water. The piston in this pump is also made of a piece of india-rubber tube, but it is tied in the middle, so as to bewider at each end; it prevents in this form the passage of water in both directions. The small board to which the pump is attached should be clamped to the table, so as to have both hands free; one for working the pump, the other for directing the jet.

Both pumps may properly be closed at the top by corks, which serve as guides for the piston-rods; the holes in the corks should be as wide as to permit the rods to move in them easily and without jerks.

An india-rubber tube drawn over the lower metal tube may serve as suction-tube instead of a glass one; but it should be firmly tied to the metal tube, or it will not close air-tight at the joint.

30. *The Reaction of Efflux in Gases. Phenomena of suction.*—When gaseous bodies flow through the aper-

ture of a vessel, reaction of efflux takes place as in liquid bodies. The ascent of a rocket is due to the reaction of the gases generated by the lighted powder

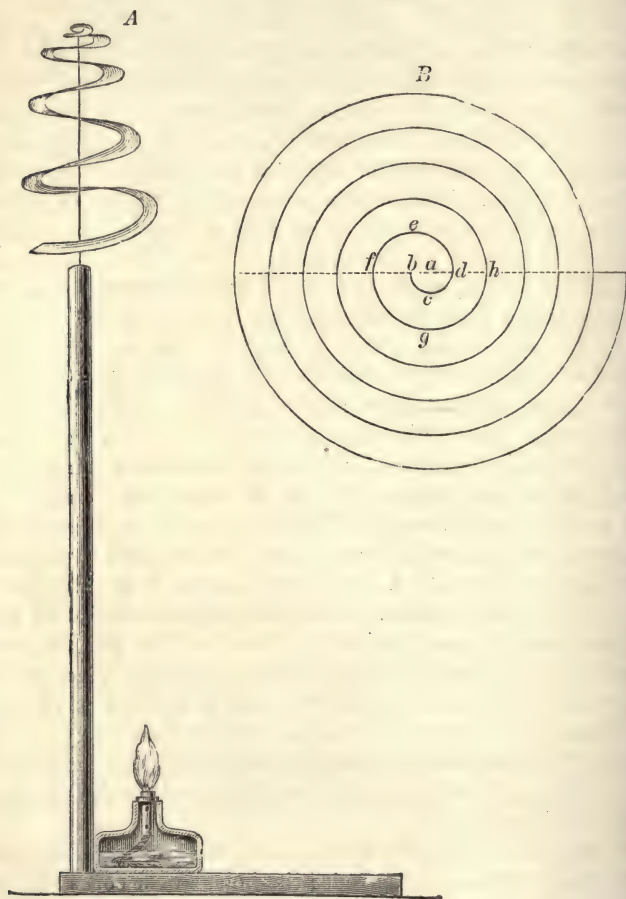


FIG. 200 (*A*, $\frac{1}{8}$ real size; *B*, $\frac{1}{2}$ real size).

the motion of the rocket taking place in a direction opposite to that in which the gases are issuing; to the same cause are due the rotatory motion of a catherine wheel and the erratic movements of a squib.

reaction-wheel, which is driven by steam, will be described hereafter.

Screw-propellers act in air as well as in water. The sails of a windmill are applications of the principle on which the action of the screw depends, on a larger scale; on a small scale the same principle is applied in the toy-mill, which is set in motion by presenting its sails, made of wood or feathers, to a current of air. Fig. 200 *A* represents a spiral cut out of paper, and balanced upon a knitting needle. If an ascending current of air is produced by placing a spirit-flame underneath it, the spiral begins to rotate, precisely in the same manner as the screw opposed to a current of water, which was shown on page 202, fig. 145.

Fig. 200 *B* indicates how the spiral is drawn upon a piece of stiff paper. From the centre *a* describe the semicircle *bcd*; from *b* the semicircle *def*, and again from *a* describe *fgh*, and so on. With the blunt point of a knitting needle make a shallow cavity in the paper, between *a* and *b*, and cut the spiral. Fix the knitting needle in a hole made in the top of the retort-stand with the bradawl, place the cavity of the spiral upon the point of the knitting needle, and the spiral will assume by its weight the form shown in fig. 200 *A*.

When a light wheel provided with blades, like those of a screw-propeller, is set in rapid rotatory motion, and is not fixed, it will not only have a progressive motion, but it will even ascend in the air. The 'flying tops,' and 'boomerang tops' sold in toy-shops, are applications of this principle; the wheel in most of them may be set in rapid motion by means of a spring which acts within a case; as soon as the little wheel leaves the spring, it darts off into the air, and continues to rotate for some time by its inertia. Another kind of flying top is made to

rotate by rapidly unwinding a string wrapped round the axis of the wheel.

Cut a circular disc of very thin tin-plate, about 9^{cm} in diameter make a hole in the middle, and make six incisions from the margin

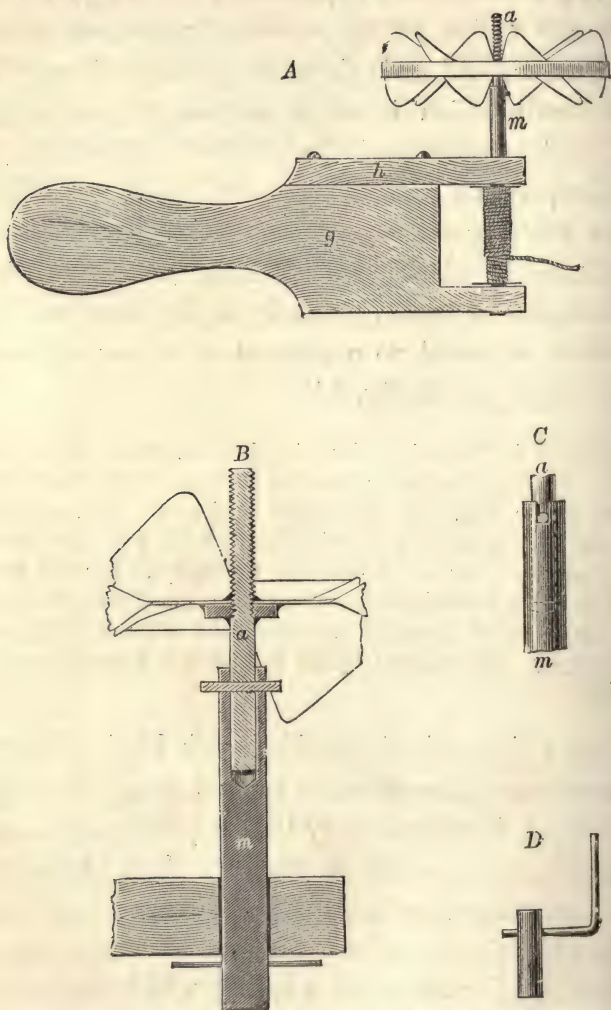


FIG. 201 (*A*, $\frac{1}{3}$ real size; *B*, *C*, *D*, real size).

which do not quite reach to the centre, as in fig. 146 *B*, page 20. Bend the blades, as in fig. 146 *A*, and round off the corners; if lo

with sharp angles they might possibly injure objects against which the wheel flies. To keep the blades in position and prevent their being bent out of shape, solder round them a ring made of two strips of tin-plate 6^{mm} wide, each being 15^{cm} long, if the diameter of the wheel is 9^{cm} . The ring is formed of two strips, in order that it may be soldered at two opposite points; if there were only one joint, the ring would be heavier on that side than on the other. The ring should allow of being pushed over the wheel with moderate friction; the two strips, while they are being soldered to the blades should be kept in position by bending an iron wire round the ring and twisting the ends together, for the first joint is apt to break while the other is being made. The wire is removed when the solder is cool and firm. Fig. 201 *A*, shows the wheel with the contrivance for letting it off; *B* gives a section through the middle of the wheel and its support. The axis is formed by a piece of steel wire, 3 or 4^{mm} thick, and 4^{cm} long, with a screw cut upon it from the top to the middle; 1^{cm} below the middle a hole is bored through the axis, having a width of $1^{\text{mm}}5$. A disc of brass, 1^{cm} in diameter, and 2^{mm} thick, is screwed upon the axis, and a brass wire, 1^{cm} long, is passed through the transverse hole. The disc forms the support for the wheel, to which it must be soldered as well as to the axis. As the axis is apt to break away unless it is firmly fixed, the disc cannot be dispensed with, and it is not advisable simply to solder it upon the axis without screwing. The brass wire must also be soldered into the hole.

Bore an aperture, 15^{mm} deep, into one end of a piece of brass wire, *m*, which has a thickness of 6^{mm} and a length of 9^{cm} , the aperture being wide enough to admit easily the axis *a*. File a notch 3^{mm} deep, across the aperture, and wide enough to receive conveniently the brass wire which passes through the axis; this portion is shown more distinctly at *C* than at *B*. The brass piece is further perforated across its thickness, 12^{mm} from its lower end, and two discs of brass, 6^{mm} wide, are soldered to it, one 1^{cm} from the lower end, the other 1^{cm} from the upper one; the intermediate portion of the brass wire forms thus a short spindle. Two pieces of wood, of the form *g* and fig. 201 *A*, are procured from a joiner; they should be about 12^{mm} thick, and each have a hole at the projecting ends, 6^{mm} in diameter; after passing the brass wire through the holes, the piece *h* is fixed to *g* by two screws.

One end of a thin but strong cord, $1^{\text{m}}5$ long, is then passed through the lower hole and wrapped in smooth and close turns round the spindle; there should be thirty turns forming two layers. A small handle, shown in fig. 201 *D*, made of a small piece of steel wire,

3 or 4^{mm} thick, with a piece of brass wire passed through a hole in it, and bent at right angles, renders the wrapping on of the cord more easy; the handle is placed in the hollow at the top of *m* and replaced by the wheel as soon as the cord is wrapped round the spindle. The cord should of course be wrapped round the spindle in such a manner that, on unwinding it, the wheel is turned upward into the air; in the figure the wheel is a left-handed screw and (looking down upon it from above) it must be turned from left to right, as the hands of a watch move, in order to make it rise upwards; the cord must therefore be wrapped on from right to left and if the small handle be used it must be turned in a direction opposite to the motion of the hands of a watch. The last turn of the cord should be close to the disc of metal, so that it may be pressed between the latter and the preceding turn, and the cord be thus prevented from unwinding itself.

When everything has been thus prepared, the part *g* is held in the left hand, the arm is stretched out horizontally and the cord firmly pulled off by the right hand; the wheel will rise in the open air about 10^m, and return to the ground again after 6 or 8 seconds. In a room it rises to the ceiling, rebounds and returns to the floor where it continues to spin round like a top.

Remarkable phenomena may be observed when liquids and gases flow through tubes which become suddenly wider at one point, or when gases escape from orifices into the open space. If water flows in vacuum through a tube, which becomes wider at a short distance from the end, the jet will either pass freely through the widened part, without filling it, as shown in fig. 202. Or, if considerable adhesion should exist between the tube and the liquid, the latter would flow along the side wall of the tube in the wider part of it, as represented at *B*. If the orifice be closed for a short time the wider portion of the tube becomes completely filled, but when the orifice is opened again the efflux proceeds as before, as soon as the quantity of water collected in the wider part has been discharged. The reason of this is easily understood. If a liquid passes through a tube

at a given rate, each particle of the liquid moves with a definite velocity, that is, it passes onward through a certain number of centimetres in every second; if liquids pass at the same rate through two tubes which differ in width, a greater quantity of liquid will evidently pass

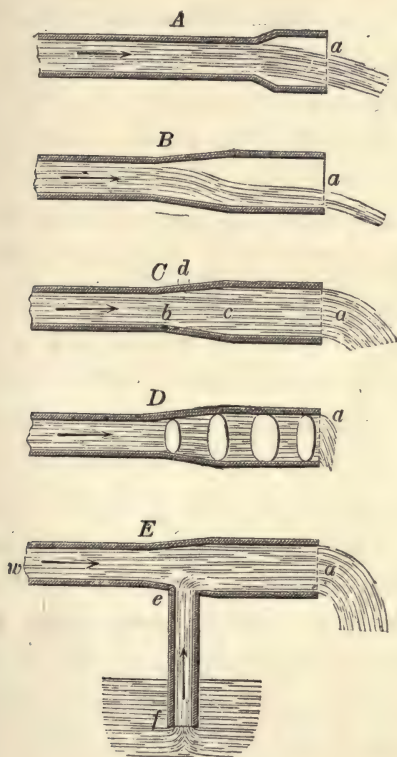


FIG. 202.

in the same time through the wider tube than through the narrower. Conversely, if the same quantity of liquid is to pass during the same time through two tubes of unequal width, the rate of motion, or velocity, of the liquid passing through the narrower tube will

have to be increased. Now, in this case, the velocity of the liquid remains the same when it reaches the wider part, as a consequence of the inertia of the liquid particles, the jet therefore maintains its previous dimensions in width, and does not fill the wider portion of the tube.

The case becomes somewhat different, when the flow takes place in air. Left to itself, the efflux of the liquid takes place in precisely the same way as shown in fig. 202 *A* and *B*, for the efflux in vacuo. But if the orifice *a* be now closed for a short while, and then opened again a jet will issue, having the full dimensions in width of the orifice, fig. 202 *C*. It is the pressure of the external air which now prevents the partial emptying of the wider portion; for if the issuing jet is to have the greater width of the full orifice and the water is to flow out with the same velocity which the particles possess the liquid would be expected to break up into detached portions, between *b* and *c*, fig. 202 *D*, but the vacuous spaces which would thus arise, are rendered impossible by the pressure of the external air at *a*. The water issuing now in a thicker jet, must have a diminished velocity; while on the other hand the liquid particles tend to maintain their previous velocity, and to separate from one another between *b* and *c*. The consequence of this is that the pressure between *b* and *c* is considerably diminished, and this decrease of pressure may be so great, with a suitable form of the tube, and a sufficient velocity of efflux, that the pressure within the tube in that portion actually less than that at *a* where the liquid is discharged. The pressure at *a* must of course be greater than the atmospheric pressure, or no liquid

would flow out ; but between b and c the pressure may be considerably less than the pressure of the atmosphere, and hence, if an aperture be made at d , no water will flow out, but air will enter the tube, and the jet will assume again the form, fig. 202 *B*. If, instead of at d , an aperture be made at the lower side at e , and a tube ef , fig. 202 *E*, of moderate length be inserted in the aperture, while the other end dips in water, the

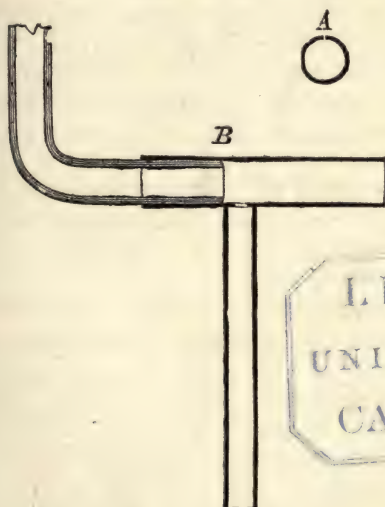


FIG. 203 (*real size*).

pressure of the atmosphere upon the free surface of the water will cause the latter to ascend in the tube ef , and to flow out with the water discharged by the tube va .

These effects of efflux through tubes which become suddenly wider at one point, are usually termed '*phenomena of suction*;' they are produced by other liquids as well as by water.

The pressure necessary for the required velocity of efflux is best obtained by means of the reservoir, described in art. 27 (page 255) but a column of water, 1^m high, is also sufficient to produce the necessary velocity in a glass tube 4 or 5^{mm} wide. The latter should have walls about 1^{mm} in thickness, and is provided with a discharge tube, made of sheet zinc, and just wide enough to pass over the glass tube. There is no strain on the zinc tube, and it is not necessary to solder the edges over one another; the edges are brought close together, as in fig. 203 *A*, moistened with soldering water, a small piece of solder placed upon them and cautiously heated; when it melts the solder flows of itself along the edges, fills the interstices between them, and thus closes the joint. A narrower tube of the same metal, 4 or 5^{cm} long, is soldered to the former, 20^{mm} distant from the end at which the water is to be discharged. The narrower tube must not be inserted into the wider tube, but must be fixed externally to it; it should therefore be made curved at the top by filing so as to correspond to the surface of the tube to which it is to be soldered. The narrow tube is best prepared by using a cylindrical piece of wood or metal, upon which the sheet metal is hammered into a tube with the mallet; a tube which is made by simply bending the metal is rarely smooth and round. The sheet zinc may be rendered softer before working it, by heating it to the temperature at which solder melts. When the narrower tube has been fixed to the wider, the latter is attached to the glass tube; the glass tube is first heated, a layer of sealing-wax placed upon the hot tube, and allowed to cool; the metal tube is then heated, and pushed over the glass tube. If this order of proceeding in fixing the tubes upon one another is not strictly carried out, a quantity of sealing-wax is apt to be squeezed into the zinc tube, and the latter would become narrower at the precise spot where it is to be wider than the glass tube; to avoid such an emergency it is further necessary to leave the edges of the end of the glass tube which is inside the zinc tube sharp, instead of rounding them off. This end should be very near to the aperture which leads from the wider into the narrow zinc tube, as shown in fig. 203 *B*. The part of the glass tube which is bent upwards is connected, at a height of 1^m above the orifice from which the water is to issue, with some such contrivance for supplying the tube with water, as is shown in fig. 141 (page 197) or fig. 155 (page 225). It is, however, better to connect the bent tube with a separate tube, 1^m long, by means of a short india-rubber tube, with sealing-wax. The width of this tube should be 8^{or} 10^{lines}; such a wide tube is not easily broken by the weight of the water in the funnel, or other contrivance for filling it at the top, while it is

held in the retort stand, and offers, besides, less resistance by friction to the passage of the water through it than a narrower tube; the velocity of the water hence becomes greater. If a reservoir is used, the glass tube may be left straight, 8 or 10^{cm} long, and in order to connect it firmly with the india-rubber tube which leads from the reservoir, a short piece of a wider glass tube, which corresponds to the width of the rubber hose, should be fixed with sealing-wax over the end of the straight glass tube.

A capacious vessel (a basin) is placed near the mouth of the tube for the reception of the discharged water. The narrow zinc tube is dipped in water contained in a saucer and coloured red by magenta. The supply of water being provided for, if necessary with the help of an assistant, the finger is placed at *a* as soon as the liquid begins to flow out, and held over the aperture until the air is squeezed from the apparatus, and has escaped from the zinc tube. The finger is then removed from *a*. A full jet will issue from the orifice, which will be reddened by the admixture of the water from the saucer, and if the discharge be maintained for some time, the saucer will be completely emptied. The finger should not close the aperture *a* but only render it narrower; if *a* be closed the air would not be removed, and the water would flow into the saucer.

A current of air which flows from a narrower tube into a wider one, produces suction in a similar manner as a current of water. If air be strongly blown into the narrower tube of the contrivance represented in fig. 202 *E*, at *w*, or in fig. 203 *B*, water will be made to ascend in the vertical tube and will be thrown out at *a* in small drops.

The effect of suction produced by a current of air is rendered especially obvious, if the current is allowed to expand between two flat discs, such as those in the little apparatus, fig. 204 *A*. A circular disc of cardboard, 10^{cm} in diameter has a hole in the middle. A glass tube, about 8^{mm} wide, bent at right angles, is passed through a cork which is glued upon the disc, so that the bore of the tube is exactly over the hole in the disc. A second disc, of stout paper, or thin cardboard,

is suspended to the other by three threads; the distance between both discs should be 10^{mm} . If air is strongly blown through the tube, it will expand between the plates in a radiating manner, as shown by the arrows in fig. 204, *B*, and the particles of air will tend to move

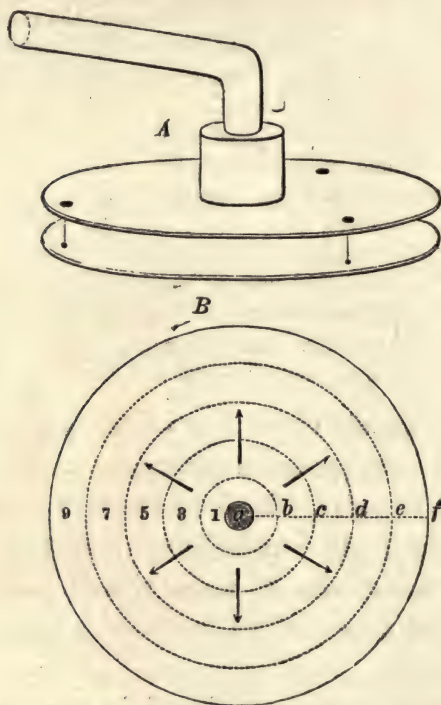


FIG. 204 (*an. proj.* $\frac{1}{2}$ real size; *B.* $\frac{1}{2}$ real size).

with the same velocity, that is, a particle at *b* tends to reach *c* in the same time in which it moved from *a* to *b*, and to pass from *c* to *d* again in the same time, and so on. But if the particles of air are to maintain the same velocity, then the same quantity of air which at an instant fills the space within the circle 1, will in the

next instant have to fill the space within the ring 3, in the next that within the ring 5, and so on. Now the areas of the circles drawn in fig. 204 *B*, with radii of 1, 2, 3, 4, and 5^{cm}, are $1 \times 1 \times 3.14$, $2 \times 2 \times 3.14$, etc., or 3.14, 12.56, 28.26, 50.24, and 78.50 square centimetres, and the areas of the successive rings between the circles are

$$12.56 - 3.14 = 9.42 = 3 \times 3.14$$

$$28.26 - 12.56 = 15.70 = 5 \times 3.14$$

$$50.24 - 28.26 = 21.98 = 7 \times 3.14$$

$$78.50 - 50.24 = 28.26 = 9 \times 3.14$$

If the particles of air are to maintain their original velocity, it is necessary that the quantity of air which at a certain time fills the inner circle of 1×3.14 square centimetres area, should fill at the following instant, the ring of 3×3.14 , at the next instant the ring of 5×3.14 centimetres area, and so on : that is, the same quantity of air must successively fill a space 3, 5, 7, 9 times as great as at first, and must hence diminish its density and consequently its pressure so as to become from $\frac{1}{3}$ to $\frac{1}{9}$ of what it was in the centre of the circle. The pressure of the air which passes through the tube into the space between the discs is thus, although originally greater than the pressure of the atmosphere, gradually becoming less while radiating out, and escaping at the edge, and becomes actually less than the atmospheric pressure. It is true, that the velocity of the air particles decreases from the centre to the edge, and the diminution of pressure is not quite so great as would appear from our calculation, because the external air opposes a considerable resistance to the

escaping current, but the ultimate effect is that the pressure over the greater portion of the space between the discs is less than the external pressure of the atmosphere: hence the remarkable result that the external air presses the suspended disc against the current blown from the tube and moves it close to the fixed disc, and not until the current of air diminishes in strength will the disc fall back again.

A similar expansion of a current of air, which flows from an aperture under a pressure somewhat greater than that of the external air is always observed, even if the issuing current is not made to spread out in any definite manner as it is in the last experiment. A liquid which issues from an orifice, forms a jet of nearly uniform thickness; but a gas blown through a tube forms, in expanding, a cone; as can be well seen in the case of smoke or steam. The particles move first in straight lines forwards, but being at first denser than the external air they become gradually less dense by expansion, and move away from one another sideways, and this lateral motion continues as long as the pressure is unequal. But in consequence of the inertia of the moving particles the lateral motion continues even a short time after the pressure is equalised, and the issuing gas becomes less dense than atmospheric air, and consequently its pressure also becomes somewhat less. The resistance of the external air, exerted principally in front of the issuing current, soon restores in the latter the atmospheric pressure, but at a spot near to the orifice, a diminished pressure may be actually observed: at this spot air enters from the sides, mixes with the issuing current, and is carried onwards with it.

If the end of a tube is placed opposite to that portion of a gaseous jet, the air flows to it through the tube, and even heavier particles may be carried onwards by the jet.

If the wide end of a bent tube, fig. 205, is dipped in water, and air is blown through the straight tube, the liquid rises in the tube until it reaches its mouth, and is there carried away and dissipated by the air current, the drops forming a conical spray.

A glass tube, 9 or 10^{cm} long, 2 or 3^{mm} wide, is pulled out in the middle, cut, and one portion bent so as to form an obtuse angle. Both are then passed through suitable holes in a cork, so that the

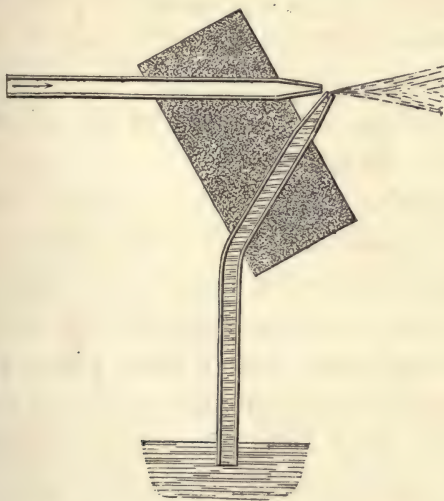


FIG. 205.

point of the bent tube is a little in front of the end of the straight piece, as shown in fig. 205. If the apparatus does not act well at first, pull the tubes in and out until the position is found in which they act best.

If a strong current of air is blown by means of a glass tube, a few centimetres long and 6 or 8^{mm} wide,

across the upper end of a glass or paper tube (the latter can be made by rolling a piece of paper over a glass tube and pasting the edges upon one another), from 0.5 to 1^m.5 long and 8 or 10^{mm} in diameter, in such a direction that the angle between the tubes is a little more acute than the angle between them in fig. 205, a cork, small enough to fall through the longer tube easily when it is held vertically, will, if placed inside the lower end, rush up the long tube towards the end upon which the air is blown, and will dart away in a curve.

The liquid and the cork are driven by the external pressure through the tube towards the spot where the issuing gaseous jet has a pressure less than the atmospheric pressure.

A current of steam exhibits more strongly such phenomena of suction, than one of air, as will be shown in the chapter on HEAT.

31. *Molecular phenomena in gases.*—*Condensation upon surfaces.*—*Absorption.*—*Diffusion.*—Gaseous bodies manifest adhesion upon solid bodies; they are attracted and held so strongly by solid surfaces that a kind of condensation takes place. The larger the surface of a solid body, the greater is the quantity of gas which may be condensed by it; hence porous bodies are capable of condensing so much, that they appear to absorb it. This kind of attraction is not manifested to the same extent by all solid and gaseous bodies. It is especially remarkable between carbonic acid and charcoal. A piece of charcoal absorbs a volume of carbonic acid, many times larger than itself. If a small glass vessel full of carbonic acid be inverted in mercury, so that its mouth dips below the surface

and a small piece of charcoal be introduced, the mercury rises upwards into the vessel, in consequence of the external pressure, and finally fills it completely.

Carbonic acid is made by placing a quantity of small pieces of marble of the size of a hazel-nut or pieces of unburned limestone or even chalk into the apparatus for making gas, shown in fig. 154; the bottle is half filled with water, closed by the cork, and hydrochloric acid is poured in through the funnel. The gas is generated with effervescence, similarly as in the case of hydrogen. To prevent the liquid from frothing a small quantity of acid is poured in at first, 10 or 20^{cc}, and more of it is added when the evolution of the gas becomes slower.

The vessel shown in fig. 162 is filled nearly to the edge with mercury and the liquid then poured through a wide funnel into an empty bottle, from which a small test-tube (about 8^{cm} long and 1^{cm} wide) is quite filled and the remainder poured back into the iron vessel; the reason of this manipulation is to bring into the iron vessel a quantity of mercury which will just allow the vessel to receive afterwards in addition the contents of the test-tube. The test-tube is now closed by the finger, inverted, and its mouth placed below the surface of the mercury. It should now be carefully clamped in the retort stand, which has been set ready for the purpose, so that its mouth may be a few millimetres from the bottom of the vessel. Beneath the lower aperture of the test-tube is placed the end of a short piece of glass tubing which has been drawn out into a point, the other end of which is connected by a piece of india-rubber tubing with the tube issuing from the gas-generating apparatus. The carbonic acid rises in small bubbles to the top of the test-tube and fills it gradually, while the mercury flows out.

The gas which first issues from the apparatus should not be conducted into the test-tube, for it is mixed with air. Fill a bottle, about the same size as the gas apparatus, with water, and dip its mouth below the surface of water contained in a basin. Attach a small glass tube to the tubing of the apparatus and place it underneath the mouth of the inverted bottle. Fill the bottle with gas, and you may then safely assume that all the air has been swept out of the apparatus and that the gas which now issues is pure carbonic acid. For delivering the gas into the test-tube a different piece of tubing from that which served for the delivery of the gas into the bottle should be used, for the latter is wet, and water would thus be introduced into the test-tube, and would fill the pores of the charcoal and so interfere with the success of the experiment.

Charcoal absorbs not only carbonic acid but also air, although in a less degree. The pores of common charcoal which has been prepared for some time are hence always filled with condensed air which evidently must be removed before the charcoal is capable of manifesting distinctly its absorptive power for carbonic acid. This is done by holding the piece of charcoal to be used (cut about 12 or 15^{mm} long and 6 or 12^{mm} thick) with the forceps over the point of the flame of a spirit lamp or a Bunsen's burner until it is red hot: the heat causes the absorbed air to escape. To prevent the piece of coal from absorbing air again, it is at once placed red hot into the mercury under the mouth of the test-tube, which together with the retort stand is slightly raised for this purpose so that the piece of coal may be pushed into the gas. Care must be taken not to raise the tube above the surface of the mercury, or the carbonic acid would escape while air would enter. The stand is then immediately lowered again, and the absorption of the gas proceeds so rapidly that in a few minutes the mercury fills the tube at the top of which the charcoal may be seen.

Charcoal may be purchased in suitable pieces, or prepared by putting a small log of soft wood, but not too small, into the fire, and letting it burn until it is completely reduced to glowing coal and no longer burns with flame. It is then withdrawn from the fire and closely covered with ashes or sand, until it is extinguished; or it may be put into water, but in that case it must be first completely dried before cutting a piece suitable for the present experiment, because wet charcoal bursts when heated. In the experiment above described, the pores of the charcoal become partially filled with mercury: the mercury so absorbed may be recovered by pounding the charcoal in a mortar, stirring up the powder with water, and pouring it off from the globules of mercury.

The surfaces of all solid bodies, are, under ordinary circumstances, covered with an invisible layer of condensed air, and of condensed vapour of water, which is always contained in atmospheric air. Clean a glass plate and let it stand a few hours, so that a layer of air may be condensed upon it. Write upon it with a piece of hard wood or a brass or iron point (not a steel one which scratches glass). The adhering air is then removed from those places which have been written upon.

breathe upon the plate, and the writing will be seen.

rendered visible, because the vapour contained in the breath is deposited unequally upon the clean portions of the glass and upon those still covered with condensed air. As soon as the deposited vapour disappears, the writing disappears also, but appears when the plate is again breathed upon, and this will even be the case for a day after. In order to remove the layer of air uniformly, the plate must be strongly rubbed with a piece of cloth all over the surface ; the capability of the plate to re-

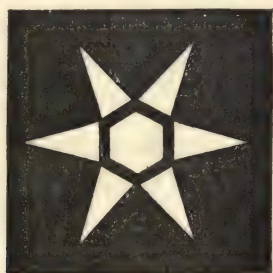


FIG. 206 ($\frac{1}{2}$ real size).

produce the writing is by no means destroyed by merely wiping the surface with the cloth. A simple mode of producing such 'breath figures' is, to cut in stiff paper a figure with not too delicate outlines, for example a star, as in fig. 206. The paper is then placed upon a glass plate and breathed upon, so that the portions of the glass where the paper has been removed are covered with vapour. When this vapour, after the paper has been removed, is allowed to evaporate, so that nothing is seen of the figure, it will immediately reappear on breathing again upon the plate, although in this case the figure cannot be reproduced as many times as in the former case. The explanation of this phenomenon rests on the fact that the adhering layer of

air upon that portion of the plate which was covered with the paper is in a different state from that which has been breathed upon.

A common window pane will serve for this experiment, provided it be not too warm, in which case no vapour would be deposited upon it. It should be rubbed, in order to remove the air from it, with a clean dry cloth, applying strong pressure but rubbing slowly, so as not to heat the plate too much. A loose pane which may be placed upon a flat surface (layers of paper upon a table, or something similar) is not so easily broken. The experiment does not succeed so well with glass not previously well cleaned.

A similar attraction takes place between the molecules of liquids and gases; liquids are equally with solids capable of absorbing gases. The absorption of a gas by a liquid is mostly called solution. Water dissolves various gases in different quantities, but of the same gas there is always less absorbed by hot water than by cold water. Fresh spring water contains a quantity of air in solution; if it is allowed to stand in a glass, in a room so that it gradually becomes warmer, a portion of the air separates in small bubbles which adhere to the sides of the glass. The separation of the dissolved air may be observed still better by heating water in a test-tube but not so much as to make it boil. Best of all it may be observed, by placing a glass of fresh water under the receiver of an air-pump and exhausting it; for a liquid is capable of holding greater quantities of a gas in solution, when under great pressure, than when the pressure is diminished. Hence a diminution of pressure has the same effect as an increase of temperature. Effervescing drinks, such as soda-water, champagne beer, hold considerable quantities of carbonic acid in solution. This gas is generated during fermentation.

or is forced into the liquids by means of pumps which produce great pressure, as is the case with artificial mineral waters. In a corked bottle containing such a liquid, great pressure is exerted upon the surface by the gas, as long as the bottle is closed ; but, on opening the bottle, the compressed gas above the surface of the liquid escapes, and the pressure sinks to that of the atmosphere ; in consequence of this diminution of pressure, the dissolved gas escapes in large quantities, the liquid frothing up and effervescing.

The absorption of carbonic acid by water may be shown by means of a test-tube, of a size which just allows the mouth to be closed with the thumb. It is filled with water, inverted mouth downward into a vessel filled with water, and filled to about three-fourths with carbonic acid. As soon as this is done, the mouth is closed with the thumb under water, the test-tube is taken out, thoroughly well shaken, its mouth again placed in the water, and the thumb withdrawn. Even before this, the thumb is perceptibly pressed into the mouth of the tube by the pressure of the external air, which is greater than the pressure inside the tube. A considerable force will be required to open the tube under water, and when this is done, water enters it to supply the place of the absorbed carbonic acid. The tube may be again withdrawn, and the shaking repeated ; each time more carbonic acid will be absorbed, until finally nearly the whole space inside the test-tube is filled with water.

Gases exhibit the phenomena of *diffusion* more generally than liquids, because all gases form mixtures with one another, while many liquids cannot be mixed. Gases

mix even if the lighter of two gases is on the top of the heavier, as may be shown with carbonic acid gas. This gas is about one and a half times as heavy as atmospheric air, and differs also from the latter in not being a supporter of combustion: a burning splinter of wood is immediately extinguished when introduced into it.

Carbonic acid may be collected by placing the mouth of the tube leading from the generating apparatus close to the bottom of a tall and wide glass vessel. The gas being heavier than air, collects at the bottom of the vessel, and rises gradually until it has completely filled it. The depth to which the gas has risen may be easily ascertained by inserting a burning splinter. If the vessel is quite full, the flame will be extinguished when the splinter dips only a very short distance below the top of the vessel; but if it is not quite full, the splinter will not be put out until it is immersed to some depth—that is, until it actually dips into the gas. That carbonic acid is heavier than air may be well shown by the fact that it may be poured from one vessel into another like a liquid: a piece of burning candle is placed in a vessel; another vessel, of about the same size, filled with the invisible gas, and held obliquely over the first vessel in the same manner as in pouring out a liquid: the heavy gas flows into the other vessel and extinguishes the candle.

This experiment can of course be made only in a room with closed windows and door; the slightest draught drives the gas to the side of the vessel. The vessels should be rather tall, about 20^{cm} high and 12^{cm} wide. The small piece of candle or taper may be fixed to the bottom of the vessel, or attached to a piece of cork, which, if necessary, should be hollowed out below, so as to adapt it to the usual curved form of the bottom of glass vessels.

If carbonic acid is left to stand in an open vessel, and after some time a burning splinter be introduced into the vessel, it will continue to burn, thus proving that the gas has escaped from the vessel. The carbonic acid, though heavier, has diffused into the air above it, although the latter is lighter, and the diffusion has proceeded far more rapidly than it proceeds between liquid bodies ; for, half an hour after filling the vessel, all carbonic acid has escaped.

The diffusion between different gases also takes place more rapidly than between liquids if they are separated by a porous partition ; both classes of bodies are, however, alike in this, that the lighter substance passes more rapidly through the partition than the heavier. It is usual to denote this kind of action between gases by the term 'diffusion,' while the analogous phenomenon in the case of liquids is commonly spoken of as 'endosmose.'

A partition made of plaster of Paris is very suitable for experiments on diffusion. A glass funnel, having its wide mouth closed by a plate of plaster of Paris, may be filled with carbonic acid, by placing it, stem upwards, upon a glass plate, and inserting through the stem a narrow tube, which is attached to the india-rubber tube of the apparatus for making the gas ; this tube must be long enough to reach to the widest part of the funnel, as shown in fig. 207, *A*. When the funnel may be supposed to be full of gas, it is lifted together with the glass plate, the end dipped into water (fig. 207, *B*), and the glass plate is removed. Carbonic acid will now pass out through the plaster wall, but the lighter air flowing inwards with greater velocity, increases the

volume of gas contained in the funnel ; the consequence is, that bubbles of gas escape from the end of the funnel and rise through the water (fig. 207, *C*). If the funnel, while covered with the glass plate, and in an upright position, be filled with coal gas, or still better

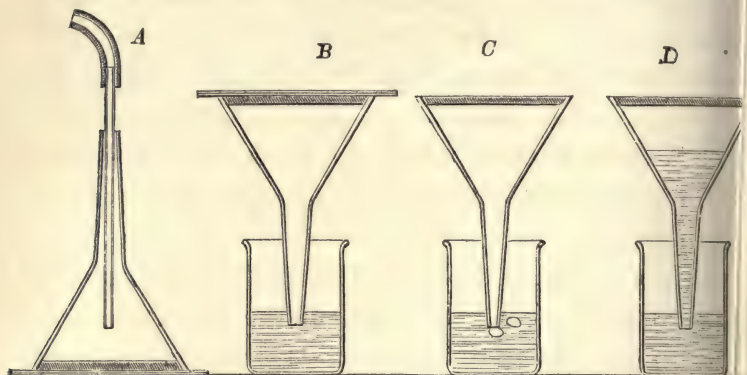


FIG. 207 ($\frac{1}{3}$ real size).

with hydrogen, and the end dipped into water, the lighter gas will diffuse outwards more rapidly than the heavier air enters inwards : the volume of gas in the interior diminishes, and in the course of a few seconds the water rises to about half the height of the funnel, as shown in fig. 207, *D*.

The mouth of the funnel should be 6 or 8^{cm} wide. A plate of glass, somewhat larger than the mouth of the funnel, is placed horizontally upon the table, and soft plaster of Paris is poured over it (*vide* p. 157), so as to form a layer 2 or at most 3^{mm} thick. If the mass does not flow well, tapping of the glass plate or striking upon the table will assist in spreading it. As soon as the layer is sufficiently thin, the funnel is placed upon it and the edge pressed through the plaster, so as to cut out a disc of it, and then left in position. Half an hour after, the plaster round the funnel is removed with a knife, and air blown through the tube ; by this means the funnel may easily be lifted. The glass plate should be left to stand in the sun or in a warm place for a few hours before an attempt

made to remove the disc; when this is accomplished, the disc is placed upon three small corks and left a whole day, so as to dry thoroughly. The rim of the funnel is now heated, by holding it over the lamp and constantly turning it, until hot enough to melt sealing-wax, and a layer of sealing-wax is placed round the inside of the rim. The funnel is then allowed to cool until the wax has partially hardened, and it may be held nearly straight without the wax running down on the inside; the thin lining of sealing-wax originally put round the rim is now made thicker with a piece of sealing-wax heated over the lamp; the whole edge is again uniformly heated, and the funnel is inverted over the disc of plaster. After cooling, the wax which has been squeezed out is scraped off with the knife. If the funnel is not quite round, it should be placed in the same manner upon the disc as it was in the first instance when the disc was cut out; otherwise the latter will not fit properly into the mouth of the funnel.

For the experiment with carbonic acid, the funnel should dip only a few millimeters into the water, so as not to obstruct unnecessarily the escaping gas-bubbles. For the experiment with coal gas or hydrogen the tube must dip somewhat deeper, or the end of it would be above the surface of the water when the latter rises in the funnel.

ACOUSTICS.

32. *Nature and Propagation of Sound.*—The phenomena of Sound, which form the subject of study in the science of Acoustics, are classed together under one name, in the first instance because they are perceived by us through one particular organ of sense—the Ear. The primary meaning of the term sound may accordingly be defined as any external action capable of exciting in us the sensation of hearing. When, however those actions, which we perceive as sound, are examined as to their physical nature, it is found that they all consist essentially in *motion*. In many cases this is easily recognisable by the touch; thus, for example, when sound is produced by a piano, or a violin, or a tuning fork, a vibratory motion may be felt in some parts of the sounding bodies. These vibrations are not accidental; if they are prevented by mechanical means, the sound ceases. If the vibrating strings of the piano, or those of the violin, or the prongs of the tuning-fork, be touched with the fingers, the sound is immediately stopped.

In order that a sounding body may be heard it is not sufficient for it to perform appropriate movements; it is necessary that these movements should be imparted to the ear. The movements of sounding bodies are propagated in most cases by the air, sometimes also, but much less frequently, by liquid or solid bodies. The

transmission of the motion which constitutes sound must, however, be distinguished from the progressive motion of the air itself, produced by various other causes; just as the advance of waves on the surface of water is distinct from the onward flow of the water. A small body floating upon the wavy surface of water is lifted up and down by the waves, but it has little or no movement backwards or forwards. Each wave as it glides onward under the floating body, moves it with its front a short distance forward in the direction of its motion; but as soon as the crest of the wave has passed beneath it, the body returns again upon the back of the wave into its former position, the displacement forwards being precisely equal to the subsequent displacement backwards. Whenever a floating body has a continuous progressive motion, this is due to some other cause than the action of the waves, such as the pressure of the wind, or to the actual flow of the water in which the body floats.

Careful experiments have shown that, when a uniform series of waves follow each other along the surface of water, the particles of the liquid which are disturbed by them move in elliptical or circular paths, and that hence each particle returns again to the point from which it started, while the onward motion of the whole wave is due to the fact that each liquid particle commences its motion somewhat later than the preceding one.

Fig. 208 is intended to illustrate the formation of waves by the circular motion of the individual particles of water. For the sake of clearness, only a few particles are represented in the figure, those which are shown being so far apart that each one begins to move when the

preceding one has completed the twelfth part of its circular motion ; the portion of its path which each particle has already described at the instant to which each figure corresponds is shown by the dotted curves. *A* represents the surface after the particle 0 has moved through one twelfth of a circle ; *B* represents the surface after it has moved through two-twelfths and the particle 0 through one-twelfth of a circle. In *C* the particle

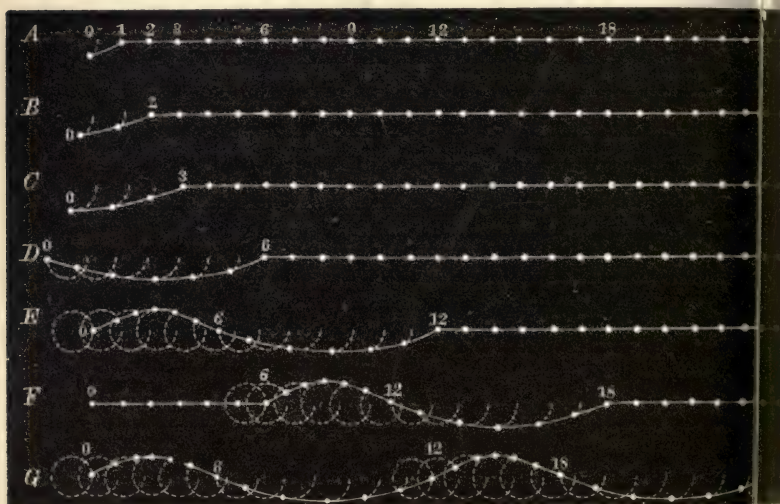


FIG. 208.

has passed through three-twelfths or one-fourth of the circle ; in *D* it has described a semi-circle, and in *E* it has returned to its original place. If only a single wave passes over the surface, each particle comes to rest after describing a circle. *F* represents the surface at the moment when the wave has moved onward through half its whole length further than it was in *A*, and if there are successive waves, each particle repeats its motion, as shown in *G*.

The motion of the particles of air during the propagation of sound resembles to some extent that of the particles of water during the propagation of a wave ; hence sound is said to be propagated by an undulatory or wave-like motion of particles of air.

The resemblance is, however, confined to the fact that each particle performs the same definite movement but commences its motion somewhat later than the preceding one. The path described by each particle is essentially different in the two cases. When a wave is propagated through water, each particle describes a circle ; when sound is propagated through air, each particle of air moves in a straight line, backwards and forwards, in the direction in which the sound is propagated. A wave of water is formed by a series of crests and hollows, (or elevations and depressions) ; a wave of sound, by a series of alternating compressions and rarefactions of air. Such compressions and rarefactions of the air must take place whenever a body, surrounded by air, is set into rapid vibrations—that is, when its parts are made to move rapidly to and fro through a short space. Suppose a tuning-fork to be struck, and, for the sake of simplicity, that one of its prongs vibrates exactly in the direction towards and away from us. As soon as the prong commences to move towards us, the nearest particles of air (*a* in fig. 209, *A*) are compressed, while the particles farther away at *b* are as yet unaffected by the impulse in consequence of their inertia. Before the prong commences its backward motion, the compressed particles of air expand again, and the expansion takes place in that direction in which they meet with the least resistance—that

is, in the direction towards *b*—because the particles at *b* are under the ordinary pressure, while those

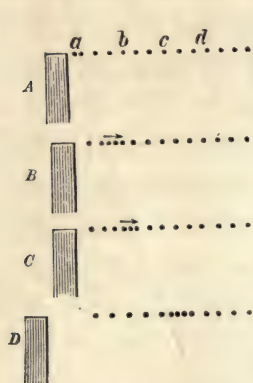


FIG. 209.

situated close to the vibrating prong are in a state of condensation. Compression now takes place at *b* (*B*, fig. 209), the particles at *a* moving in the direction of the arrow. By their inertia the particles maintain this direction of their motion even for an instant after the prong has already commenced its backward motion—the is, away from us (fig. 209, *C*). At

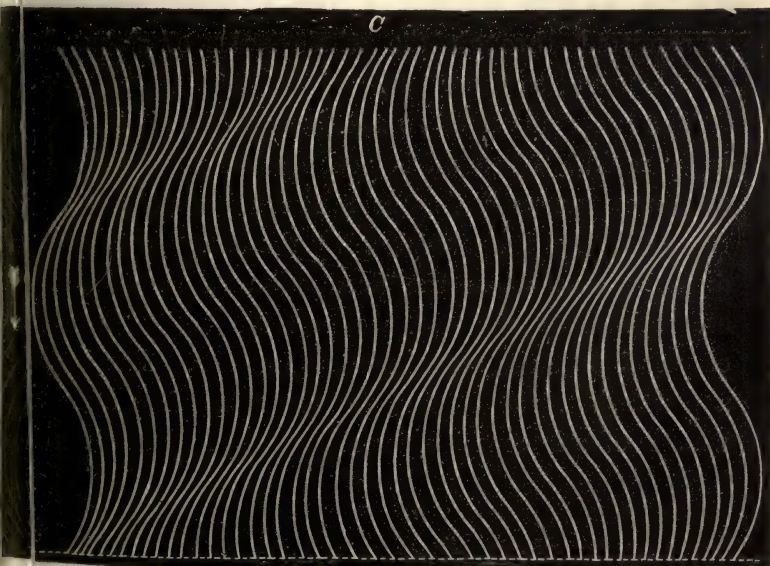
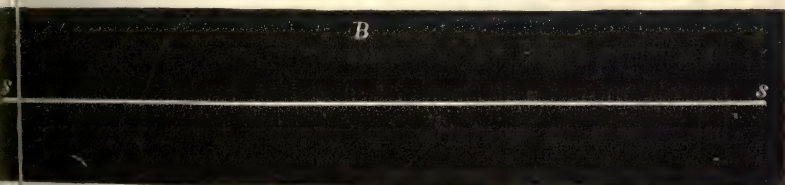
that moment the particles at *b* are already moving towards *c*, and cause a compression of the air at *c*, while the particles between *a* and the prong suffer rarefaction because the prong moves to the left while the particles *a* move to the right. But as soon as this takes place and the air close to the prong becomes rarefied, and considerably less pressure than the still somewhat compressed air at *b*, then the particles *a* reverse the direction of their motion, and move towards the prong (fig. 209, *D*); the rarefaction is now between *a* and *b*, while the compression proceeds beyond *c* towards *d*. At the air has now again acquired the original density. In this manner the compression continues to approach us, and is followed by the rarefaction, which advances in a similar manner, because the particles now at *b* flow towards the rarefied part, causing a rarefaction at *b*, and so on.

The tuning-fork does not perform merely a single vibration, but the vibrations are uniformly repeated, and

FIG. 210.

a series of condensations and rarefactions follow each other in rapid succession, and are propagated to our ear; the last particle of air close to the ear vibrates to and fro, exactly like the particles close to the prong of the fork, only a little later.

The motion of the particles of air during the propagation of sound may be further demonstrated with the help of fig. 210. A narrow slit *ss* is cut out of a piece of stiff paper (*B* in the figure), which is either black, or at any rate of a dark



colour; the piece of paper is then placed upon *A*, so that the slit is exactly along the dotted line. The book is now slowly drawn along in the direction of the arrow, the piece of paper being held in the same position. At first the lower extremity of the curved line on *A* is seen through the slit; but as the book is drawn along, the portions to the right, and those to the left come successively in view. The small white dot which is the only visible portion of the curved line appears as a point which moves first to the right and then to the left, and imitates closely the motion of a vibrating particle of air, the rate of motion being, however, much slower. If now the slit is placed over the dotted line in *C*, fig. 210, and the book is drawn along underneath it in the direction of the arrow, a representation is obtained of the motion of a series of particles of air which are acted on by a number of successive equal undulations or waves. Each particle merely moves a little right and left, and always comes back again to its starting-point; but the condensations and rarefactions, represented by the lines being respectively closer together or farther apart, are gradually transmitted through the whole series of air-particles from one end to the other.

The propagation of sound through the air is exceedingly rapid. If sound is produced at a short distance, no time apparently elapses between the production of the sound and its perception by the ear. At a great distance, and when the production of sound cannot be ascertained by the eye, we perceive easily that time elapses before the sound reaches our ear. The flash of a pistol-shot, the column of steam issuing from the whistle of a locomotive, is seen perceptibly earlier than

the report or the whistling is heard, if the observer is at a distance of several hundred, or still better several thousand, feet. Even at a distance of 200 feet, the sound produced by a person striking a hard object, such as a stone or a log of wood, with an axe or a hammer, is not heard at the instant when the object is seen to be struck, but the sound is heard sensibly later. The velocity with which sound is propagated has been determined by observing the time which elapses between seeing the flash when a very distant gun is fired and hearing the report. The average velocity thus found is 340^m per second; it is somewhat smaller in cold air, and somewhat greater when the air is warm.

From the interval in time between lightning and thunder, during a thunder-storm, the distance of the thunder-cloud may be approximately estimated. Thus an English mile is about 1609^m , and sound requires therefore $\frac{1609}{340} = 4.73$ seconds, or very nearly $4\frac{3}{4}$ seconds, to travel an English mile. To pass over 4 miles, 19 seconds are required, or nearly $\frac{1}{3}$ of a minute; similarly, if between lightning and thunder there is an interval of say half a minute, we may conclude that the thunder-cloud is at a distance of $\frac{30}{4\frac{3}{4}}$ miles, or a little more than 6 miles.

Air is the most usual conductor of sound, but not the best. Many solid bodies transmit sound very well and much better than air. The transmission of sound can be strikingly shown by means of a tightly-stretched piece of twine, or still better an iron wire. Each end of the cord or wire is fixed into the middle of a thin

but not very small board called a *sounding-board*, which in consequence of its comparatively large surface and great elasticity is peculiarly capable of receiving sonorous vibrations from the air, and, conversely, of communicating its own vibrations to the air. With sounding-boards of three or four square decimetres area and a length of about 100^m of twine stretched between them, the slightest tapping of a pencil or the finger upon the board at one end can be distinctly heard at the other end. A musical-box, set playing upon one board, is heard at the opposite as distinctly as if it were close to the ear. Words pronounced in a low voice at a distance of 10^{cm} from one board are perfectly audible to an ear placed near the board at the other end.

If an iron wire, about 0^{mm}·6 thick, be very tightly stretched between two sounding-boards, it is possible to transmit the gentlest knocking of the finger, or the sound of words spoken moderately low, over a distance of more than 600^m. If several persons transmit words in this manner, the difference in their voices is distinctly recognised. A short sharp cry produced within 1^m from the board is heard twice at the other end: the first being due to the transmission of the sound by the wire; the second, which arrives a little later, is transmitted by the air, the propagation through air taking place more slowly than that through the wire.

Common wooden cigar-boxes having a size of about 25^{cm} in length, 14^{cm} in breadth, and 8^{cm} in height, may be used as sounding boards. The top is removed, and the four sides left to make the thin bottom firmer. Better still are sounding-boards made of veneer of pine-wood, 1·5 or 2^{mm} thick, glued to frames which are about 20^{cm} long and 2^{cm} high; the sides of the frames, which are best made by a joiner, should have a thickness of about 6 or 8^{mm}.

In the middle of each board a hole is made, 2 or 3^{mm} wide, the end of the wire drawn through it, wound round a piece of brass or iron wire, about 3^{cm} long and 2^{mm} thick, and the end twisted round the straight portion of the thin wire. If the communication is made by cord, the ends are tied firmly round the crosspieces. The sound-

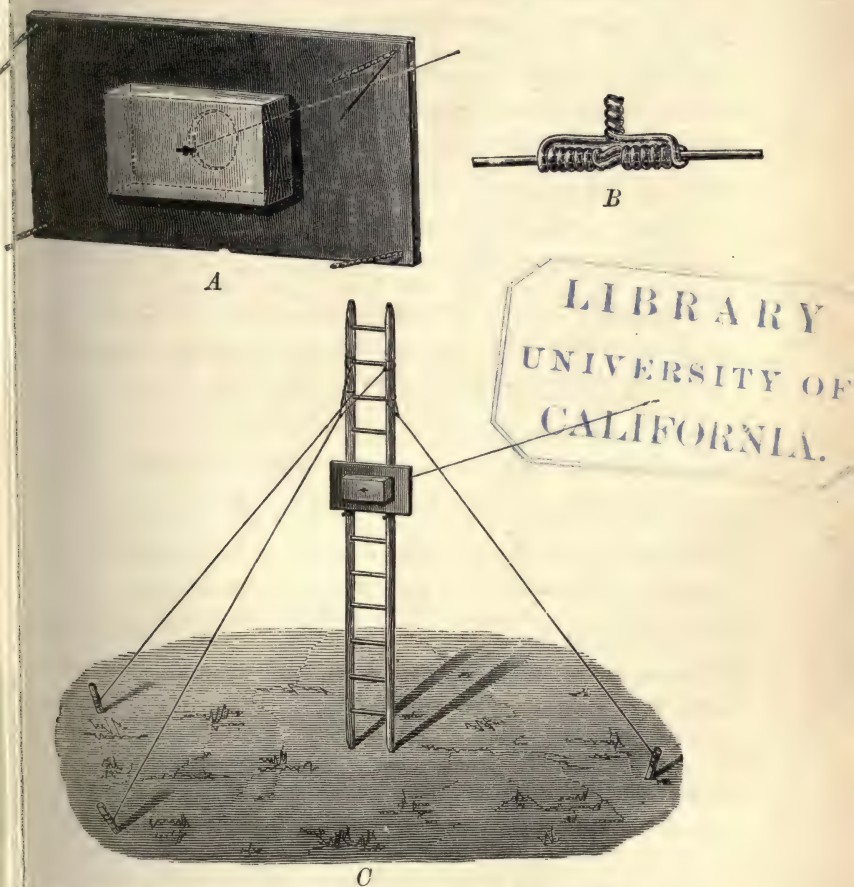


Fig. 211 (A, an. proj. $\frac{1}{10}$ real size; B, twice real size; C, an. proj. $\frac{1}{50}$ real size).

g-boards, or sounding-boxes, as they might be called on account of the frames, should be placed with the frames turned towards one another, the crosspieces of stouter wire being on the free sides which are turned away from each other.

If the experiments are made with twine of not more than 100^m in length, the two observers may simply each hold one of the boxes

with both hands close to their faces, stretching the twine as tightly as possible without breaking it or the thin boards. To hold them long is, however, tiring, and the tapping could not be done without the assistance of a third person; it is therefore more convenient to fix the boards otherwise. This may be done by using the opposite windows of two houses, 100 or 150^m distant from one another. Each box must then be supported upon a board (fig. 211, *A*), about 0^m·5 or 0^m·6 long, and a little wider than the box; each board has a square or round hole cut through it, 6 or 8^{cm} wide through which the cord passes freely. The boxes are kept in position by a few pins driven close to them into their supports. If the sash of the window is raised, it will be easy to adjust the board so that it is held by the sash and the frame of the window, if the cord is stretched. The opposite board may be similarly supported, but as the thread cannot be tied until afterwards, it has not the required tightness when fixed, and the board must be pulled back. This may be done by boring holes at the four corners of the board, fixing cords to them and pulling the cords tight, and attaching them to a hook in the wall, or the handle of the door. The board which carries the sounding-box may then be left quite free, or it may be supported by the back of a chair. The cord which transmits the sound must be perfectly free throughout its length. Another mode of supporting the boxes is shown in fig. 211, *C*. Two small ladders are erected in the open air, and kept steady by stretched ropes, which are either fastened to trees or to pegs driven into the ground. The boards with the sounding-boxes are supported by the nails driven into the ladder, and the communicating cord passes between two of the rounds.

Iron wire is better than twine, and allows of experiments being made over a greater distance, but as it sinks considerably in the middle in consequence of its weight, it requires somewhat high points of support. It may, however, be supported in the middle in the following manner. Two rather long poles are driven slanting into the ground, so as to cross near their top; where they cross a piece of twine is tied to them, and the wire is supported by the twine, so as to pass between the poles one or two decimetres below the crossing. The stretching of a wire which is several hundred metres long, is rather troublesome and requires several persons; great care must be taken that the wire is pretty nearly straight at the outset, and especially that it has no kinks, or it will break when tightened. It will generally be necessary to put together a wire of such a length as is required, by joining several pieces: the ends should be annealed and twisted together in the manner shown in fig. 211, *B*.

Attention should be paid to the position of the short cross wires which hold the ends of the communicating twine or wire; they should be placed parallel to the longer sides of the boxes.

The sonorous vibrations which in the first instance are communicated to the sounding-box either by the air or by striking it, or by a sounding body, such as a musical box or a tuning-fork, placed in contact with it, are communicated by the sounding-box to the end of the twine or wire, and are propagated by the latter just as they would be by the air. Each particle performs a very short oscillation to and fro, and impels the next particle to make a similar movement. The last particle of the wire transmits the motion to the elastic sounding-board, and the latter, in consequence of its large surface, to the surrounding air. The reason that in these experiments a weak sound is heard at a greater distance than it is in air, is not strictly speaking the better conducting power for sound possessed by solids as compared with air, but it is that the sound is transmitted by the twine or wire only in one direction, and therefore with undiminished intensity; whereas in air sound is propagated in all directions around its source, and therefore diminishes in intensity. A similar effect may be observed on throwing a stone into a pond; the circular wave which spreads out from the point where the stone strikes the water, becomes more and more shallow as it recedes; but if a wave is produced in a long wooden trough, such as is sometimes used for conveying water, in any very narrow water-channel with straight smooth sides, the wave will be seen to move on through considerable distance without sensibly diminishing in height.

Sound transmitted by air will be propagated with nearly undiminished strength if the sonorous vibrations are prevented from spreading in different directions. A tube of sheet metal, open at both ends and about 3 inches wide, may be used for showing this fact. The aerial vibrations produced by speaking into such a tube are prevented by its sides from spreading all round, and run through the length of the tube losing only little of the intensity by the friction of the air against the sides, and by the vibrations which they communicate to the tube itself. Such tubes, called 'speaking-tubes,' are in common use wherever sound has to be transmitted over considerable distances or between separate rooms, as on board ship, in hotels, manufactories, etc. The transmission of sound through such tubes is not interfered with by their passing through walls, ceilings, etc., nor is the intensity much diminished by angles and bends in their course. Smaller flexible tubes are often used with advantage by deaf persons as 'ear-trumpets,' one end being inserted in the ear, while the person speaking holds the other end, which forms a funnel-shaped enlargement, near the mouth.

The effect of such a tube can easily be observed by inserting one end of an india-rubber tube a few meters long, and 6 or 8 mm wide, into the tube of the ear, so as to be in close contact with the auditory organ. If now a tuning-fork be gently struck by another person, and held near the other end of the tube, the sound is heard as distinctly as if the tuning-fork were close to the ear itself. If a tuning-fork is not at hand, the slight sound produced by rubbing together the edges of two finger-nails may be substituted.

The 'speaking-trumpet' is much less effective than speaking-tubes and ear-trumpets. It is conical, much wider at one end, and provided with a mouthpiece at

the other. It is used to prevent the sound of words spoken at the narrower end from spreading out in all directions and to cause it to be transmitted chiefly in the direction towards which the wide end is turned.

The difference between the propagation of sound through air and the mere motion of translation of air may be shown by a small apparatus constructed in the following manner:—

Bend a piece of strong pasteboard into a cylinder, about 10^{cm} wide, and 15^{cm} long, or even longer, and glue the edges over one another; fix upon one end, with glue, a lid, with a circular hole in the middle, 2 or 3^{cm} in diameter; close the other end by a piece of stout paper (such as is used for packing or drawing), which is drawn very tight over the end and then tied with thread; the paper must first be wetted and stretched over the end just when the gloss arising from the wetting has disappeared. Before using the apparatus it must be perfectly dry. An apparatus made of brass is better and more durable, and a piece of calf-skin or ox-bladder answers better than paper. The cylinder must have a projecting rim at the open end, so as to allow of the cover being tied firmly, otherwise it will slip off.

If the elastic cover be tapped moderately strongly with the finger, a small quantity of air is expelled from the apparatus with considerable force, and moves through some distance. If the apparatus be filled with smoke, by thrusting a piece of burning tinder stuck upon a wire through the aperture, which is held downwards until the tinder is consumed, the smoke expelled by knocking with the finger upon the other end issues as a beautiful ring, moving first with great but afterwards with diminishing velocity, and becoming gradually larger. Similar rings are often produced on a smaller scale by smokers, by blowing the smoke away in successive jerks. The rings are best seen when the apparatus

is held horizontally in a line with the eye, so that they are seen as they gradually recede, or by placing oneself opposite to the apparatus and at some distance, so as to see them as they gradually approach. It will be at once seen that the air, although in this case propelled with considerable velocity, travels much more slowly than sound. At a distance of from 2^m to 4^m from the apparatus and opposite to it, an observer does not hear the sound of the knocking sensibly later than the person who produced it and is close to the apparatus; but he sees the rings approach quite leisurely, and he feels their impact if they strike his face, while the impact of sonorous waves is not felt unless the sound is of extreme loudness, as, for instance, the report of a discharged cannon. With such a ring the flame of a candle may be blown out at a distance of 2^m or 3^m, and at even a greater distance with a larger apparatus, if a portion of the circumference of the ring reaches the wick; but a much louder sound than that caused by the knocking of the finger would have no effect whatever upon the candle. The essential nature of the propagation of sound is a series of successive condensations and rarefactions of the air spreading out in all directions, whereby each individual particle of air is merely caused to move backwards and forwards through a small distance; hence the objects upon which the oscillating particles impinge are not perceptibly moved. But in the experiments with the smoke-ring apparatus the whole mass of air which is propelled moves onward in a definite direction, and its collision with bodies which are in its own path produces an effect which is comparatively great. Thus a piece of paper suspended

Two threads to the arm of the retort stand is set into visible motion by it.

When a drop of water is allowed to fall upon the middle of the water contained in a circular basin or plate, the wave thus produced is seen gradually to enlarge and to spread in the form of a ring until it reaches the side of the vessel; here the wave does not disappear but it returns again, forming a ring which becomes

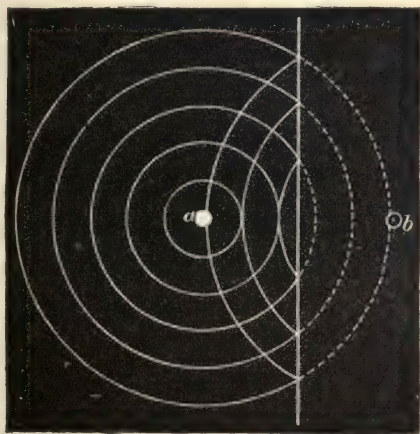


FIG. 212.

gradually narrower and contracts at the middle. We may in this case say that the wave is *reflected* by the side of the vessel. If the 'reflection' takes place at a straight wall, such as the side of a square trough, the reflected wave does not return to the point from which it started but spreads out backwards, after reflection, in the same manner as if it had been produced at a point as far behind the wall as the point where it was really produced is in front of the wall. Fig. 212 shows what is seen as the result of producing successively several

waves at *a* ; the reflected waves spread as if they were produced at *b*.

Waves transmitted by solid bodies are also capable of being reflected if they reach the surface of another body. If a piece of cord, 5^m or 10^m long, is tied at one end to a fixed point (a hook or a door-handle), and the other end is held by the hand, the cord being moderately stretched so as just to be horizontal, and that end is slightly jerked either downwards or to the side, an undulation will be transmitted along the cord which is seen to return after having reached the opposite fixed point. If both ends of the cord are fixed and the latter plucked somewhat aside by two fingers placed near one end, the wave is seen to travel backwards and forwards several times, being repeatedly reflected at each end. If, in the experiments on the propagation of sound, an iron wire a few hundred metres long be used, and a single vigorous knock be given to the sounding-board with a small stick, the sound will be heard at each end six or eight times, its intensity gradually diminishing. The wave which travels along the wire is repeatedly reflected at each end. The reflection cannot be perceived distinctly with short wires, because the velocity of propagation in iron is extremely great, and hence the wave returns so rapidly to the starting-point that the ear is unable to distinguish the rapidly succeeding sounds.

When sound-waves, which are propagated through the air, meet with any obstacle, as for instance a large solid surface, the waves are reflected. This reflection produces the *echo*. Solid bodies with a small extent of surface also reflect sound-waves, but to

reflected sound is too feeble to be heard without special contrivances, and for the production of a distinctly audible echo the wall of a large building is at least required. Beautiful echoes are produced by the straight boundaries of forests, the grandest of all by the steep sides of rocky mountains. Numerous feeble echoes are continually produced in the streets of towns, but are scarcely ever noticed during day-time, being overpowered by the general noise; but in the night, when the streets are quiet, a short sound produced by stamping the foot against the pavement or by clapping the hands, is followed not only by one but frequently by several echoes. If the street is narrow, the sound should be produced at one side, not in the middle of the street, so that it may have to travel the whole available distance to the reflecting surface. If we suppose the reflecting wall to be 17^m (about 23 paces) distant from the point where the sound is produced, the time required for the sound to reach the wall is $\frac{17}{340} = \frac{1}{20}$ th of a second; an equal length of time is required for the reflected sound, or (1 second will elapse between the production of the sound and the perception of the reflection. This interval is so short, that the primary and reflected sound can only be distinguished if the original sound was very sharp and quick, and sufficiently strong; if these conditions are not fulfilled, as for instance in calling out a person's name, the direct and the reflected sound are confounded. When the distance of the reflecting surface is greater, the reflected sound will return after a longer interval of time, and according to the length of this interval whole words, in some cases

even a short melody played on a trumpet, will be reproduced by the echo. Multiple echoes can be produced in two different ways—namely, either by the repeated reflection of a sound backwards and forwards between two parallel surfaces, such as two walls standing opposite each other; or when there are several reflecting surfaces at different distances from the ear, so that the separate echoes are heard one after another.

33. *Number of Vibrations. The Siren. Pitch.*—The sensations of sound are of great variety. Independently of the varying intensity of sounds, the most striking difference is that between a *noise* and a musical note or *tone*. A noise is produced either by a single powerful explosive disturbance of the air, as, for instance, by a sudden blow, or the report of a pistol—or several disturbances interfere with one another so as to produce confused waves in the air, as for instance in those sounds commonly designated as rattling, rustling, hissing, etc.; in which the vibrations follow one another either at irregular intervals or so slowly that each one can be perceived separately. A tone or musical note, on the contrary, is produced by vibrations which follow each other rapidly and at regular intervals.

It has already been stated that the particles of a sounding body have a vibratory motion. The particles oscillate like a pendulum on either side of a definite position of equilibrium, completing each vibration in a definite length of time, which continues the same as long as the motion lasts. The space traversed by each particle of a sounding body and the time required for one vibration are, however, much smaller than in the

case of a pendulum. If a body makes 500 vibrations in one second, then 500 is called the *number of vibrations* made by the body, and $\frac{1}{500}$ of a second is called the *time of vibration* of the body. A knowledge of the absolute number of vibrations made by a sounding body is needful to enable us to make a closer acquaintance with the essential nature of musical sounds. The

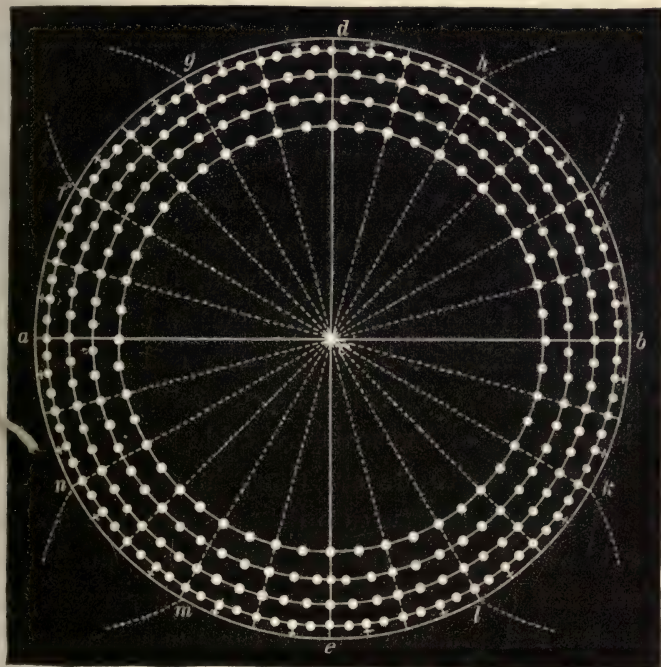


FIG. 213 ($\frac{1}{3}$ real size).

determination of the number of vibrations, by the direct observation of ordinary sounding bodies, presents many difficulties ; an apparatus used for the purpose, the *siren*, facilitates this determination. By the siren a great variety of notes is produced, not by setting a body to vibrate but by producing a series of puffs of air which

follow in rapid and regular succession. In its most simple form the apparatus may be constructed by fixing to the whirling table a circular sheet of mill-board, in which several concentric rows of holes are punctured in circles round the centre, as shown in fig. 213. To correspond with the size of the whirling table previously described, the disc should have four rows of 48, 60, 72, and 96 holes respectively. If air is blown by the mouth into one end of a small tube, having the same internal width as the aperture of the holes, while the other end is held opposite to the line of openings close to the disc, the current will be interrupted and little air will flow out, when the card-board is against the jet, but it will pass wherever an aperture comes opposite it. If the whirling table is turned, the current will be stopped and opened as many times in each second as there are apertures which pass the end of the tube in the same time. Thus if the row of 48 holes be used, and the handle of the whirling table be worked so as to make the disc rotate six times in one second, then $6 \times 48 = 288$ apertures will pass the jet, and the current will be interrupted 288 times during one second; 288 puffs of air follow each other rapidly and regularly, and produce on our ear the sensation of a musical sound, though no doubt somewhat rough and impure, because it is accompanied by the whizzing sound produced by the air which strikes the card-board between the holes. Sirens are constructed which are more convenient for use and produce a purer sound than this contrivance, but they are rather complicated and expensive.

The mouth of the tube being held close to one of the

four rows, let air be blown through it as steadily as possible, and the handle be worked first slowly but gradually more and more rapidly. At first no real note is heard, but only the whirring and whizzing sound of the puffs of air rushing out of the tube; but as soon as the disc turns with a certain velocity this sound is accompanied by a deep note. This happens when 90 or 100 puffs of air are produced in one second. The notes of the largest organ-pipes are produced by only thirty-two vibrations in a second, but such very deep notes are only heard with difficulty; in our experiment they are overpowered by the whizzing sound of the air, and no note is heard distinct from it, until the number of vibrations is comparatively great, and the note becomes high enough to be easily perceptible by the ear. In proportion to the velocity of the disc the note rises, until the greatest velocity is obtained which can be produced by turning the handle with the hand. If the hand is now withdrawn and the apparatus allowed to come to rest by itself, the note becomes deeper and deeper, until it is lost in the sound caused by the current of air. If, during the experiment, the velocity is maintained for some time as nearly constant as possible, the note will remain the same, or as it is expressed, its *pitch* or *tone* will remain unaltered. This experiment proves, that difference in pitch, that is, whether a note is low or high, depends on the frequency with which the pulsations of the air are produced, and that if the frequency increases the note becomes higher, if the frequency decreases the note becomes lower, or generally the pitch increases and decreases with the number of sonorous vibrations pro-

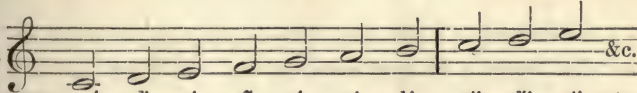
duced in a second, and notes having the same pitch whatever their origin, are produced by the same number of sonorous vibrations. In music two notes produced by the same number of vibrations in the same time, are said to be 'in unison'; no matter by what instruments they are produced. To each note a symbol or name is given, and the position of each note amongst musical sounds is determined by the *ratio* which the number of its vibrations bears to the vibrations performed in the same time by a certain other note, which may be arbitrarily chosen and is called the 'fundamental note.' Thus the particular note which is produced by twice the number of vibrations which produce the fundamental note is said to be an 'octave' higher, while that produced by half the number of vibrations is said to be an 'octave' lower, than the fundamental note. Suppose that we denote by C_1 the deepest note which our pianos usually possess, — musicians call it the 'contra-C,' — which makes thirty-three vibrations in a second, and by $C, c, c', c'', c''',$ etc. the successive octaves, then we should have for the corresponding numbers of vibrations:

C_1 is produced by 33 vibrations per second.

C	"	"	66	"	"
c	"	"	132	"	"
c'	"	"	264	"	"
c''	"	"	528	"	"
c'''	"	"	1056	"	"
c''''	"	"	2112	"	"
c'''''	"	"	4224	"	"

It is clearly possible to produce notes by any number

of vibrations, but owing to certain natural conditions of the human ear, only those notes are acceptable to the ear, when used in conjunction with each other—as, for instance, in the same piece of music—whose frequencies of vibration bear certain definite ratios to each other, or—as the same fact is expressed in the language of musicians—which form with each other certain definite musical ‘intervals.’ The whole series of sounds which are available for the formation of musical combinations, when arranged in the order of increasing frequency of vibration, constitute what is called the *musical scale* or *gamut*. The scale used in the simplest kind of music divides the octave into seven notes, each of which is characterised by the fact of its rate of vibration bearing a determinate ratio to that of the lowest note. The seven notes of each octave are designated in this country by the first seven letters of the alphabet modified, when needful, by certain additional signs, and in France and Italy by the syllables *ut* or *do*, *re*, *mi*, *fa*, *sol*, *la*, *si*. The relation between these names, the ordinary musical notation and the rates of vibration of the notes is illustrated below in the case of the octave *c'*—*c''* (see . 348):—

USUAL NOTATION.	
NAME OF NOTE.	<i>c'</i> <i>d'</i> <i>e'</i> <i>f'</i> <i>g'</i> <i>a'</i> <i>b'</i> <i>c''</i> <i>d''</i> <i>e''</i> etc.
RATE OF	{ <i>Relat.</i> 1 $\frac{9}{8}$ $\frac{5}{4}$ $\frac{4}{3}$ $\frac{3}{2}$ $\frac{5}{3}$ $\frac{15}{8}$ 2 $2 \times \frac{9}{8}$ $2 \times \frac{5}{4}$ etc.
BRATION	{ <i>Absol.</i> 264 297 330 352 396 440 495 528 594 660 etc.

This series of notes, continued upwards and downwards in the same manner, constitutes the *scale of c*: if any other note than *c'* were taken as starting point, say *g*, a series of notes having the same *relative* rates of

vibration as those indicated above would constitute another musical scale—for example, the ‘scale of *f*’ or ‘scale of *g*.’

The relative rates of vibration of the successive notes of every scale being the same, it is convenient, when discussing characters which depend only on these ratios to have some means of indicating the various notes which is equally applicable to all scales. For this purpose it is usual to speak of the *place* which any given note occupies in the scale: thus the notes in the example previously given, or the corresponding notes of any other scale, may be indicated generally as follows:—

<i>c'</i>	<i>d'</i>	<i>e'</i>	<i>f'</i>	<i>g'</i>	<i>a'</i>	<i>b'</i>	<i>c''</i>
1st	2nd	3rd	4th	5th	6th	7th	8th or <i>octave</i> .

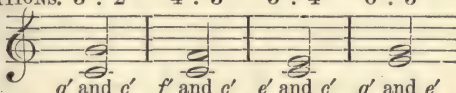
The *first* note of any scale is commonly called the *key-note* or *tonic* of that scale.

To determine by means of the siren the relation which exists between the number of vibrations and the pitch of notes, we keep the disc rotating with constant velocity, and direct the jet of air upon two or more of the circular rows of holes, either successively or at the same time, using in the latter case two or more tubes. If the disc is made to rotate $5\frac{1}{2}$ times in each second, which requires nearly $\frac{1}{12}$ ths of a revolution of the handle in our apparatus, the four notes produced will in our notation be the following:—



By sounding different notes simultaneously, we shall find that some combinations produce a much more

pleasing effect than others. The most pleasing result is attained when one note is just an octave above the other, as c' and c'' , and consequently one produces twice the number of pulsations of the other. Such a combination of two musical sounds which make an agreeable impression is called a *concord*. Next to the octave, the most pleasing concords are produced by notes the ratios of whose numbers of vibrations are those given below:—

RATIO OF VIBRATIONS.		3 : 2	4 : 3	5 : 4	6 : 5
EXAMPLE.					
	NAME OF INTERVAL.	{ Fifth	Fourth	Major Third	Minor Third.

From the number of holes in the different rows it follows that the note e' is produced by $\frac{5}{4}$ of the vibrations which produce c' , the note g' by $\frac{3}{2}$, and the note c'' by twice as many as c' . Three simultaneous notes, like our c' , e' , g' , in which the ratio of the number of vibrations is as 4 : 5 : 6, constitute a 'perfect chord.'

Whenever the disc is made to rotate with a constant velocity, though different from that previously assumed, other notes will be produced, but they will have the same constant relation to one another, and the important result will be established that the difference of pitch or the interval between two notes depends solely upon the ratio of the numbers of vibrations which produce them, whatever their absolute pitch may be. The number of vibrations made by the key-notes in the successive octaves, that is, those corresponding to C_1 , C , c' , &c., may be determined experimentally. As has been shown, each note of the higher

octave is produced by double the number of vibrations which produce the corresponding note in the preceding lower octave; and if the intervals between c' and e' , c' and f' , c' and g' , are characterised by saying that e' is the *third*, f' the *fourth*, and g' the *fifth* of the fundamental note, then notes which have the same intervals with respect to other notes will be respectively *thirds*, *fourths*, and *fifths* of these notes, the latter being considered as fundamental notes, and it follows that the number of vibrations which produce each note in the musical scale can be calculated. Thus

g' , the *fifth* of c' , makes $\frac{3}{2}$ of $264 = 396$ vibrations; e'

the *third* of c' , makes $\frac{5}{4}$ of $264 = 330$ vibrations per

second. Again, f' is the *fourth* of c' , and the ratio of the numbers of vibrations which produce these notes must be the same as that between c'' and g' , the latter being the *fourth* of the former; but the number of holes in the

outer circle is $96 = \frac{4}{3}$ of 72 , hence the number of vibrations which produce f' is $\frac{4}{3}$ of $264 = 352$. Similarly

a' , the *third* of f' , is produced by $\frac{5}{4}$ of $352 = 440$ vibrations; b' , the *third* of g' , by $\frac{5}{4}$ of $396 = 495$, and finally d'' , the *fifth* of g' , by $\frac{3}{2}$ of $396 = 594$ vibrations.

The lower octave of d'' , viz. d' , is therefore produced by $\frac{594}{2} = 297$ vibrations. We have thus obtained the

complete series for the whole scale:—

c'	d'	e'	f'	g'	a'	b'	c''
264	297	330	352	396	440	495	528

Another mode of producing a series of rapid pulsations of air is to hold one corner of a playing-card somewhat inclined against any of the series of holes. When the disc is made to rotate, the corner of the card is slightly bent between every two successive holes, but returns each time to its original shape by its elasticity; thus a note is produced which has the same pitch as that produced by blowing through the tube, but is somewhat harsher. The card vibrates to and fro as often as one of the holes passes the corner, and produces each time a pulsation of the air, the rapid succession of which causes a musical note.

If instead of the perforated cardboard a disc of metal with a milled edge be fixed to the whirling-table, very high notes may be produced by holding the corner of a playing-card against the projecting ridges. Thus suppose the edge to have 150 ridges; the handle can be turned quickly enough to give 28 revolutions in a second; the disc, we should thus have 28 times $150 = 4,200$ vibrations, or nearly the very high note c'' .

The cardboard for the perforated disc should be smooth, rather stiff, and not more than 1^{mm} thick. From the centre of the disc c , in Fig. 213, draw five circles with the radii 8.5, 9.5, 10.5, 11.5, and 12 cm; divide the whole into four parts by two diameters perpendicular to each other, ab and de ; and from a, b, d, e , as centres, and with radius 12 cm draw arcs on both sides, thus determining the points f, h, i, k, l, m, n . Join the opposite points f and k, g and l, h and i and n , by straight lines. Each circle is now divided into twelve equal parts. Divide with the compasses, by trial, each twelfth part of the second circle (counting from the centre of the disc) into five equal portions; this gives the position of the holes for the second circle. Now bisect each twelfth part of the outer circle,

and draw the six diameters, which in the figure are not lettered. Each of the circles is thus divided into twenty-four equal parts which are further subdivided as follows: on the third circle each twenty-fourth is divided, by trial, into three equal parts; on the inner circle each twenty-fourth is bisected; and on the outer circle each twenty-fourth is divided into four equal parts. This gives 12 points on the third, and 96 points on the fourth circle. The position of the 48 holes in the inner circle is found by drawing lines (not shown in the figure) between the opposite points which are marked in the figure by small crosses. The holes must be made with a *hollow* circular punch, about 4^{mm} in diameter, such as is used by saddlers for making holes in leather. Before the holes are punched in order to ensure equal distances between them, small circles about 6^{mm} in diameter, should be drawn with a small pair of compasses round each of the marked points of division; or a short piece of wire which fits into the aperture of the punch is filed to a sharp point at one end, and successively placed with its point upon the points of division; the punch is then set over it and driven through the cardboard.

It is somewhat difficult to produce a uniform motion of the whirling-table, especially when air is to be blown through the tube at the same time. It is therefore better that two persons should be engaged in the experiment, one giving his whole attention to the uniform working of the handle, the other to the blowing and the observation of the notes. For the blowing, a tube of glass or indiarubber is used, 20 or 30^{cm} long, one end being held between the lips, the other being guided by the hand.

The interval between the notes of the different rows of holes is most easily observed when the end of the tube is rapidly transferred from one row to another, so that the notes are heard in rapid succession. For blowing upon several rows simultaneously, a cork may be fixed with sealing-wax into the end of a wide glass tube through which air is blown, and the jet may be directed to the several rows by short glass tubes suitably bent, which pass through the cork; or, if an assistant works the handle, two or three tubes may be held together between the lips, and their ends directed by the hand. For blowing at the same time upon all four rows, it is best to use a hollow, pyramidal, or conical case made of cardboard or brass. The air is blown in at the smaller end, and four holes are made in the base, each 3^{mm} wide, and the same distance apart as the rows of holes in the siren. The base should measure about 4^{cm} by 4^{mm}, and the distance from it to the narrow open end should be about 15^{cm}. The box is held straight over the disc of the siren, the holes in the bottom close over the holes of the latter.

34. *Vibrations of Strings. Overtones. Resonance. Timbre.*—Musical notes are very frequently produced by the vibration of solid bodies, which, when an alteration of their form or position has been produced by the application of some force, are afterwards left to themselves. This is the case in bells, tuning-forks, drums, cymbals, the glass or steel harmonicon, &c., but especially in all stringed instruments. The investigation of the vibrations of strings throws light on many acoustic phenomena; the construction of a simple apparatus for the purpose is therefore strongly recommended.

If a cord be tightly stretched between two strong nails, which are driven into two short ledges firmly fixed to a brick wall, and the cord be plucked with the fingers, or a violin-bow be drawn across it, the cord will be seen to vibrate like the string of a musical instrument, but little or no sound will be heard. The surface of the string is so small, its points of contact with the nails are so few, that the pulsations imparted to the air are not sufficiently vigorous to produce a strong sound. For this it is necessary that the motion of the string should be communicated to a large, thin, and stiff sounding-board, as in the experiments on the conduction of sound; the sounding-board takes up the vibrations of the string and communicates them by its large surface to the surrounding air. For similar reasons, all stringed instruments are provided with sounding-boards or sounding-boxes. For acoustic investigations, an apparatus is employed called a 'sonometer' or 'monochord.'

A monochord sufficient for our purposes is shown in fig. 214. It is like a kind of box without bottom made by a joiner, if possible

150^{cm} long and 12^{cm} in breadth and height. The long sides may have a few circular apertures (*a, a*, in the figure), these, however, are not essential; the thickness of the long sides need only be about 12^{mm}, but the short sides must have a thickness of at least 20^{mm}. The four walls must be made of a hard wood, but the top board should be soft and as thin as possible; a veneer of pinewood about 2^{mm} thick is the best, but any other small board, not quite so thin, will serve for the purpose. Two triangular bridges, *b*

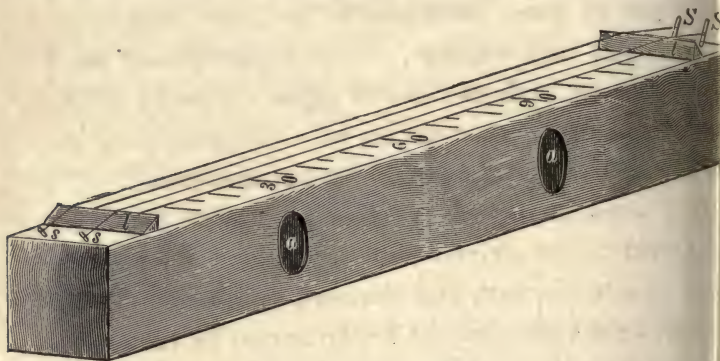


FIG. 214 (*an. proj.* $\frac{1}{8}$ real size).

made of hard wood, each 12^{cm} long, 2^{cm} broad, and 2^{cm} high, the cross section forming a right-angled triangle, are glued to the sounding-box, so as to turn their vertical sides to one another, and the slanting sides towards the ends of the box, the distance between the vertical sides being exactly 120^{cm}. If the student can not afford a smaller monochord, let it have a length of 80^{cm}, with 60^{cm} distance between the bridges. Two iron pins, *SS*, are fixed somewhat aslant into one of the short sides; wood-screws, from which the heads are removed, will serve for these pins; they are screwed in with the help of a hand-vice. The pins must be 3^{cm} from one another, and each 3^{cm} from the edge on either side. The wires which are to be stretched upon the monochord are attached to these pins by loops. Two shorter pins, *ss*, are fixed similarly at the other end of the monochord. They are made of iron wire, 1^{mm} thick, and 6 or 8^{cm} long; one end is made into a point, and a section cut up to 3 or 4^{cm} from the point; cross holes are also drilled through each pin, one hole 1^{mm} wide, at a distance of 3^{cm} from the top of each pin, and another, 2 or 3^{mm} wide, 1^{cm} from the bottom. Narrow holes for the pins must be bored in the strong side of the box, so as to require considerable force while turning them in, using

For the purpose iron cross-pins inserted into the upper holes. The end of the string is passed through the lower hole in the pin, wound round it by turning the latter several times and tightly stretched. Common piano-wires, 0·8 or 1^{mm} thick, may be used, or even unannealed iron wire. As the ends of the wires are apt to break, they should be made red-hot over the lamp; one end, heated to a length of about 6^{cm}, is bent double at half that length, and the double wire is twisted so as to leave a loop at the extremity; of the other end only about 1^{cm} need be heated, as only a short portion at that end is bent at right angles for the purpose of passing the string through the hole of the pin. Between the bridges, along the middle of the monochord, a straight line is drawn and divided into centimetres. A conspicuous mode of marking the divisions, like that in fig. 163 (page 236), will be found advantageous.

A small bar of wood, as long as the width of the monochord, exactly as high as the bridges, and about 6^{cm} wide, will be required for the experiments with the monochord.

The length of the strings is assumed in the following experiments to be 120^{cm}, which is the clear distance between the two bridges. If the monochord has only half this size the numbers which follow in the text must of course all be divided by two.

Two strings may be stretched at once upon the monochord, although only one will be required to begin with. As long as the string is rather slack, no proper note is produced, but this will be the case as soon as the string is sufficiently tight; and when the string is gradually made more and more tense, the note given out by it will be found to become higher and higher. The reason of this is, that the string, which has been pulled from its position of equilibrium by the finger, returns to the former position as soon as it is released, in consequence of the tension, and its motion is the more rapid the greater the force acting upon it, that is, the greater the tension, or the tighter the string. When the string arrives at its position of equilibrium, there is a certain amount of work in it, and by its inertia it passes to the other side of the position of equilibrium until the accu-

mulated work is expended in overcoming the resistance which the tension offers to the flexure of the string then the string returns again, performs the same motion in the opposite direction, and so on. The vibrations of a string are thus very similar to the oscillations of a pendulum, but the former are much sooner brought to an end than the latter, because the work of a vibrating string is soon expended in imparting motion to the solid bodies to which it is attached, and by means of these to the air. Other things equal, the greater the force of tension the greater is the number of vibrations performed in a given time, and the higher the note produced. If the same tension act on two strings of the same length but of different mass, the more massive string would vibrate more slowly, and the note produced would be lower. For the experiments which we have made previously on the relation of forces to the masses moved by them have proved that the motion produced by the same force acting upon different masses is slower the greater the mass acted upon. The same law holds good in the case of a vibrating string: the greater the mass moved by the force of tension, the smaller is the velocity produced, and the slower are the vibrations. To prove this relation by direct experiment, and to arrive at satisfactory numerical results, a more complete apparatus than our monochord is required. It is on account of this law that the cords of stringed instruments are made thicker for the bass than for the treble, and that those for the lowest notes are frequently rendered heavier by being wound round with thin brass or copper wire.

The string of the monochord may be shortened at w

by placing the bar of wood previously mentioned underneath it, and pressing upon the string with the finger close to the edge of the bar. The free portion now behaves like a shorter string, and if the edge of the wooden bar is placed at the division 60, the vibrating portion of the string will be half as long as previously, and its note will be an octave above the fundamental note of the string. If 80^{cm} are allowed to vibrate ($\frac{2}{3}$ rds of the whole length), the note will be the *fifth*; at 90^{cm} ($\frac{3}{4}$ ths of the whole length) it will be the *fourth*; and if the vibrating portion has successively the lengths of 120, $106\frac{2}{3}$, 96, 80, 72, 64, and 60^{cm} , the complete series of notes of the gamut will be produced.

Thus one-half of the original length produces the octave, that is, double the number of vibrations which produced the original note; $\frac{2}{3}$ rds of the length makes $\frac{3}{2}$ nds of the original number of vibrations; $\frac{3}{4}$ ths of the length makes $\frac{4}{3}$ rds of the number, &c.; or, generally, *if the tension of a vibrating string remains constant, the number of vibrations in the same time varies inversely as the length of the string.* It is a consequence of this law that in instruments with few strings, as in the violin, guitar, &c., a great variety of notes can be produced by pressing the strings with the fingers upon the 'finger board' of the instrument, thus shortening them at will, and allowing varying lengths to vibrate.

If the student has no musical ear and no good recollection for the pitch of notes, it is best to tune both strings of the monochord until an unpractised ear cannot recognise any difference in pitch between them. Both are then plucked with thumb and second finger at the same time, and if they are really in unison the sound must have uniform intensity throughout; but if this is not the case, the sound will become alternately louder and fainter. These alternations are termed *beats* (about which more will be found further on) and they

indicate a difference in the pitch of the two notes, which is the greater the more frequent the beats. One string by way of trial is made a very little tighter, and if the beats become slower, that string is still more tightened until the beats disappear altogether; if, on the contrary, the beats become more frequent, the string is slackened until they cease.

When the note of the shortened string is to be compared with the fundamental note of the unshortened one, one end of the wooden bar is placed so far under the string which is to be shortened, as to leave the other string perfectly free.

If the string be lightly touched in the middle, using the soft tip of the finger, or if the edge of a small movable triangular bridge be placed at that point, and the string be plucked near one end, the note produced will again be the octave of the fundamental note of the string; the string will be seen to vibrate on both sides of the middle point, and will present the appearance



FIG. 215 ($\frac{1}{15}$ real size).

shown in fig. 215 (in which, as in the next two figures, the flexure is, for the sake of clearness, much exaggerated).

The point touched will remain at rest; it is termed a *nodal point*, or simply a *node*, while the vibrating portions are called *ventral segments* or *loops*.

If the finger be removed after the string has begun to vibrate, the vibrations will continue in the same manner, the node will remain in the middle, and the note will be the octave of the fundamental note.

Next let the string be touched at a point distant one third of its whole length from one end (at 40 or 80 cm). Close observation will show that the string is not

divided into three vibrating portions, as in fig. 216, with two nodes. The note produced makes three times the number of vibrations of the keynote—that is, $\frac{3}{2}$ nds of

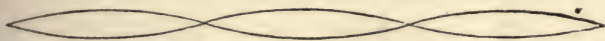


FIG. 216 ($\frac{1}{15}$ real size).

those of the octave; it is the *twelfth* above the fundamental tone, or the *fifth* above the octave.

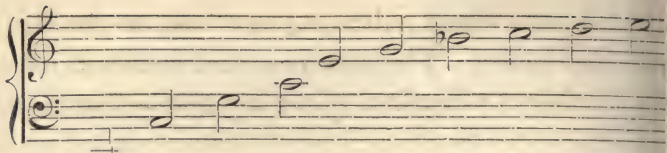
If the string is touched at 30 or 90^{cm}—that is, one-fourth of its length from one end, three nodes will be produced, the string will be divided into four ventral



FIG. 217 ($\frac{1}{15}$ real size).

segments, as shown in fig. 217, and the note will make four times the number of vibrations made in the same time by the fundamental note, that is, the note is two octaves above the key-note.

In a similar manner, the string may be divided into 5, 6, 7, 8, and even 12 ventral segments, but as a result of the whole we shall find that the number of vibrations is inversely as the length of the vibrating segments; for five segments the number is five times as great, for six, six times, &c., as the original number of vibrations. The string being 120^{cm} long, if it has a diameter of 1^{mm} and a tension of 15^{kg}, its fundamental tone will be C. If divided into varying segments, the notes produced by it will be the following:—



	C	c	g	c'	e'	g'	b' ⁷	c''	d''	e''
NUMBER	66	132	198	264	330	396	462	528	594	660
OF VIBRATIONS	=	=	=	=	=	=	=	=	=	=
PER SECOND.	2 × 66	3 × 66	4 × 66	5 × 66	6 × 66	7 × 66	8 × 66	9 × 66	10 × 66	
NUMBER										
AND LENGTH OF	1/1	2/2	3/3	4/4	5/5	6/6	7/7	8/8	9/9	10/10
SEGMENTS.										

A body is thus capable of producing notes which are higher than its fundamental tone. These higher notes are termed *overtones*; overtones of which the numbers of vibrations are whole multiples of those of the fundamental tone are termed *harmonic* overtones, or simply *harmonics*.

The string should be plucked quite close to one end, and under no circumstances at more than one point. The loops which the string makes being comparatively small, the difference between the nodes and ventral segments cannot be well seen unless the observer is quite close to the vibrating string. To render it visible, so-called *riders* are used; these are small pieces of paper about 5^{mm} broad and 15^{mm} long, bent at an acute angle (Λ), and placed astride the cord. Such a rider remains almost unmoved upon the nodal points of a vibrating cord, but is at once jerked off if placed midway between two nodes. If the cord be touched at 30^{cm}, and riders be placed at the divisions 15, 45, 60, 75, 90, and 105^{cm}, the riders upon 60 and 90^{cm} will remain upon their seats when the cord is plucked (say at 10^{cm}), while all the others are thrown off. If other segments are produced, the effect will be similar. The plucking should be done cautiously, lest all the riders be thrown off. It is better to make the cord vibrate by drawing a violin-bow across it; the riders remain in that case at rest upon the nodes even if the bow is applied rather vigorously. The bow must previously be rubbed with rosin, just as if it were used for a violin.

Tune both strings until they are in unison. Pluck or draw the bow across, one of the strings; the other string will immediately begin to vibrate without being

touched. Close to the string these vibrations are easily observed ; at a distance they may be rendered visible by riders placed on the second string, which are thrown off as soon as the first string is set in vibration ; or immediately after the first string is sounded it may be touched in several places by the fingers : its vibrations will thus be stopped, so that it can no longer produce sound, but as the note is still heard, it is clear that the second string is sounding. Vibrations communicated in this manner by one body to another are sometimes called *sympathetic vibrations*, and when the communicated vibrations produce sound, the whole phenomenon is called *resonance*. Whenever it happens that a body capable of performing independent sonorous vibrations is reached by the sound-waves of a tone of the same pitch as that which it would itself emit, resonance is produced. In our last experiment the motion of one string is transferred to the other by the intervening solid particles of wood ; but transference of sonorous vibrations may also be effected and resonance produced by the mere undulations of the air itself. Let a piano be opened and the monochord be held by two persons a little above the strings ; as soon as the fundamental note of the strings is struck on the piano, they will commence to vibrate, as may be seen by the motion of riders. When a piece of music is played on the piano, some particular note is often unpleasantly accompanied by the jingling of some object of glass or metal which is in the room. If we find out what body it is that jingles and strike it so as to make it sound, it will be found to give out the same note as that which, when played on the piano, causes it to chime in.

The jingling sound is caused by its striking against neighbouring bodies as soon as it begins to vibrate.

In order to understand how undulations of air, which are altogether imperceptible to the most delicate sensations, can produce sensible motion in heavy solid bodies, we must consider in the first instance, that such a motion is not produced in any other bodies but those capable of performing vibrations of exactly the same period as the original vibrations; further, even in such bodies, a single impulse produces a vibration which is quite insensible, although the body, in consequence of its inertia repeats the motion several times before it returns to rest; but if a new impulse is given to the body at the precise moment when it is beginning its second movement, then the next vibration will carry the body further from its position of rest than the first did; and if a great number of undulations of the air follow each other at such intervals that each one augments the movement which the previous impulses have already produced, the vibrations of the body will at last be strong enough to be easily perceived.

When several ventral segments are produced in one string of the monochord, the other string will form the same number of segments if both strings are in unison. Thus let one string be touched at 30 or 90^{cm}, and plucked at 15 or 105^{cm}, while the second string is provided with riders at 15, 30, 45, 60, 75, 90, and 105^{cm}: the riders at 30, 60, and 90^{cm} will remain at rest, while the others will be set in motion.

We may proceed conversely. Let the second string which carries the riders be touched at any of the points of division, and the first string be plucked so as

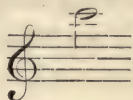
vibrate freely through its whole length, we shall find, in general, that the divided string also begins to vibrate. It follows that a vibrating string will induce vibrations in another, not only when the latter performs the same number of vibrations, but also when it makes twice, thrice, four times, &c., as many as the former; in other words, when it emits an harmonic of the first string. But, as we have previously seen, resonance can be produced only if the second body is capable of vibrating exactly at the same rate as the first; and we here see that resonance takes place when the vibrations of the second string are the harmonics of the first; hence it follows that in the note of the first string not only the fundamental tone is contained but also its harmonics. That this is really the case is proved by further investigation, which shows that a string which swings as a whole vibrates at the same time in halves, thirds, fourths, &c., of its length, and that its motion is indeed very complex. A practised ear can detect in the sound of an open string, mingled with the fundamental tone, the several harmonics to it. These overtones appear more distinct when the fundamental tone is dying away; first the octave is heard, then the twelfth, and sometimes several others besides. Different persons possess different degrees of delicacy of perception in this respect, but it is by no means absolutely requisite to possess a specially trained musical ear, in order to be able to distinguish these tones.

If the overtones of the string of the monochord are not immediately distinguished, they may be more easily heard by plucking the string and then touching a node with the finger. The fundamental tone will there-

by be silenced, while the overtones, which correspond to a node at the point touched, will not be affected since the finger was placed upon one of their nodal points ; the overtones will now be distinctly recognised without difficulty. Thus, if the vibrating string be touched in the middle, the octave above the fundamental tone will persist, together with all the tones which correspond to *even* multiples of the rate of vibration of the fundamental tone ; if the string be touched at 40 or 80^{cm}, the twelfth continues to be heard ; if at 30 or 90^{cm}, the second octave, and so on. That the overtones are not excited by touching the string is proved by plucking the string originally at a node and touching it afterwards at the same point ; for example, by plucking it in the middle, the fundamental tone will be heard very strongly, but it cannot be accompanied by the octave above it, because the point which would be a node for the octave, vibrates in this case most strongly, and if the string be now touched in the middle, all sound ceases immediately and completely.

With the help of a piano we may very easily make observations on overtones. We may then either find out the overtones of a definite note, or, which is more convenient, starting with a particular tone, we may investigate of what other notes it is an overtone. If it is desired to experiment in the former manner, gently press down one of the keys, so as to free the corresponding string from the damper, and strike repeatedly in rapid succession one of the lower keys. If the freed string belongs to an overtone of the note which is struck, it will commence to vibrate, if its key is kept down, and will continue to be heard even after the key which is struck has been released and its string has ceased sounding. If we keep on striking *C* and key after key is pressed down, the overtones of *C* will be found to be those given previously. For experiments by the converse method, it must be remembered that, since the harmonic overtones make 2, 3, 4, 5, etc. times as many vibrations as the fundamental tone, any tone is obviously an harmonic overtone of

tone which is produced by $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, etc. of its own number of vibrations. For example the tone c''' ,



with 1,056 vibrations is an harmonic overtone of the following ones :—

c''	f'	c'	$a\flat$	f	d
528	352	264	211.2	176	150.9
$\frac{1056}{2}$	$\frac{1056}{3}$	$\frac{1056}{4}$	$\frac{1056}{5}$	$\frac{1056}{6}$	$\frac{1056}{7}$

the last of which is not exactly d but slightly higher, d being produced by 148.5 vibrations. If the key c''' is kept continually pressed down, and key after key from d'' downwards is struck, allowing a short interval of time to elapse between one note and the next, the string c''' will be heard to give out its note whenever any of the above notes have been sounded. The vibratory motions of the string c''' may also be demonstrated by placing a small rider of paper upon one of the strings which produce c''' : whenever one of the notes of which it is an overtone is struck, the rider will be seen to vibrate and also heard to strike against the string. If several of the notes, of which c''' is an overtone, are struck together, for example the chord of F minor, f , $a\flat$, c' , f' , the note c''' will be heard nearly as loud as if it had been struck, even though the key c''' has not been pressed down.

It is obvious that all that has been stated above with reference to c as fundamental tone and c''' as overtone, would apply equally to any other tone; it is only necessary to calculate the other corresponding tones, or simply to count upwards or downwards the number of keys between C or c''' and the selected note: any given overtone of the note chosen is separated from the corresponding overtone of C by the same number of keys as that which separates the selected note itself from C .

Not only strings, but most other bodies emit overtones besides their fundamental tone, when set in vibration. The sum total of the tones emitted by a body may be called its note in contradistinction to the *simple tones*.

Musical notes which are produced in different ways, but have the same intensity and pitch, mostly differ in *quality*, or *character*. If we strike any note on a piano, and then sound the same note on a flute, an organ, or a violin, or utter it with the voice, we shall notice a great difference between the sounds. This difference in 'quality' or 'timbre,' or 'character,' is partly due to faint sounds which accompany the note, as, for instance, the slight sound of rushing air which accompanies the blowing of the flute, or to the circumstance that the note struck may either rapidly decrease in intensity as happens with the sounds of the piano, or it may maintain a uniform intensity as in the case of the organ. But the main cause of the difference of character is the production of overtones, which accompany the fundamental tone; these overtones not only differ in various sounding bodies, but differ even in the same body if it is sounded in different ways.

35. *Vibration of Plates, Bells, Rods, and Air in tubes.*—Solid bodies of large surface compared with their thickness perform a variety of vibratory movements if sounded in different ways. Vibrating plates contain, instead of the nodal points of a vibrating string, a succession of such points forming *nodal lines*. These nodal lines may be made visible by covering the plate with fine sand before it is made to vibrate. As soon as the vibrations commence, the sand leaves the vibrating parts, and accumulates on the nodal lines. This beautiful mode of rendering the vibrations of plates visible was suggested by Chladni, and the figures produced are hence usually termed Chladni's Figures.

For these experiments two plates are required—one square, the other circular, 12^{cm} in diameter—cut from thin window glass of uniform thickness; also a violin bow. Both plates, of which the square one should be cut by a glazier, while the second one may be prepared by the student with the help of pastille, must have their edges well ground and rounded off upon the grindstone, or they would cut the hairs of the bow. In order to hold them, a large screw-clamp is secured to the table by means of a smaller one, as shown in fig. 218. A cork from 15 to 20^{mm} high, somewhat tapering towards the upper end, which is about 8^{mm} wide, is placed below the point of the screw of the larger clamp, and the plate is supported

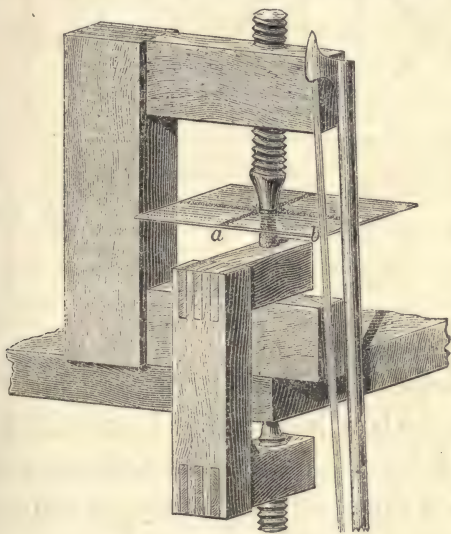
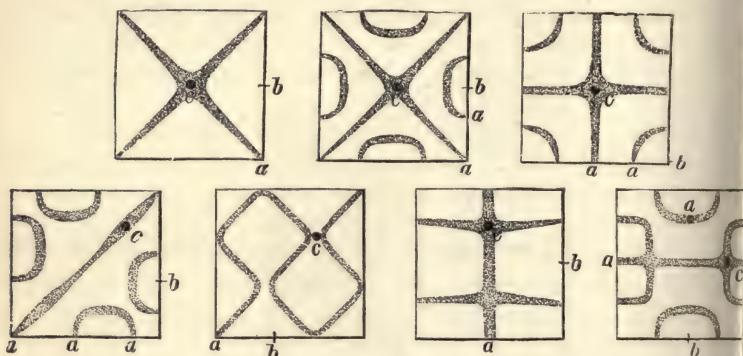


FIG. 218 (*an. proj.* $\frac{1}{4}$ real size).

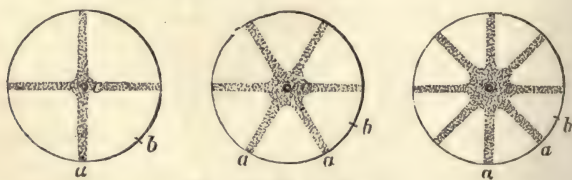
the cork. Upon the upper side of the plate a little round disc of cork is laid, also 8^{mm} wide and 2 or 3^{mm} thick, and the screw is then turned down so as to fix the whole moderately firmly together.

Let the square plate thus fixed be touched at *a* (fig. 218) with the finger and at *b* with the well-rosined bow. Draw the bow nearly straight downwards, and the figure produced will be that shown in fig. 218, viz., a rectangular cross, of which the four arms are parallel to the sides of the plate. The note given out is in this case

the deepest which the plate is capable of producing. The points at which the plate is fixed or touched must clearly be at rest when the latter vibrates, and hence these points will always be situated in nodal lines. By fixing the plate at other points, and touching it in one or more other places, a great variety of figures may be produced, of which fig. 219 gives examples; the points

FIG. 219 ($\frac{1}{8}$ real size).

touched with the finger are in all cases denoted by a , those along which the bow is drawn by b , and those where the plate is fixed by c . With a little patience the figure produced with the square plate may be infinitely varied

FIG. 220 ($\frac{1}{6}$ real size).

With a circular plate figures are most easily obtained which consist of two, three, four or more intersecting diameters, as represented in fig. 220, the letters having the same meaning as in fig. 219.

The figures will not always be produced at the first attempt. First see whether the plate is fixed precisely in the middle or at the desired point; then vary the inclination of the bow and the pressure applied to it, until you succeed. The sand should be sparingly thrown upon the plate with a castor; if there is too much, its weight impedes the vibrations. If, instead of sand, powdered blue (cobalt) glass (prepared by heating a piece of blue glass to redness and throwing it while hot into cold water, after which it can be pounded in a mortar) be used, the figures may be preserved. For this end prepare a gummed sheet of paper, carefully remove the plate from the clamp without disturbing the figure, place it on the table, cover it with the wet gummed side of the paper, lift the paper and let it dry. The sand figure will adhere and remain upon the paper.

If circular plates are made to vibrate from the centre instead of from the edges, the figures do not solely consist of various arrangements of diameters. Attach to the middle of the glass plate a small piece of sealing-wax, about 1^{ce} in size, and fix a glass tube perpendicular to the plate by means of the wax; the tube should be from 30 to 80^{cm} long, and from 5 to 10^{mm} thick. Holding the tube with the thumb and forefinger of the left hand somewhere below its middle and nearer to the glass plate, and rubbing it with the moistened fingers of the right hand, a musical note is produced; the exact point at which the tube must be held in order to produce the note most easily should be found by repeated trial. The first three fingers of the right hand, which are from time to time to be dipped in water, are used for producing the note. They are loosely placed round the tube, somewhat in the manner in which a pen is held whilst writing with it, and drawn either from the middle of the tube, which is held quite vertical, upwards to the free end, if the plate is below, or from the free end upwards to the middle, if the plate is above. In the latter position we have the advantage that no water can drop upon the plate; in the former the apparatus is used more conveniently. After ascertaining the precise point for holding the tube in order to make it sound, the plate is wiped in case it should have been wetted, sand is thrown over it, and the apparatus again made to sound. The figures thus obtained vary with the relative proportions, as to size and thickness, of the two glass parts of the contrivance. A definite combination of tube and plate gives only one definite figure when sounded. Fig. 221 shows two such figures, which are respectively produced by means of a disc 10^{cm} in diameter, and of two tubes, one 55^{cm}, the other 25^{cm} long.

Bells may be considered as circular concave plates.

They behave precisely like flat plates, and are most easily divided, by means of two lines at right angles to one another, into four vibrating parts.

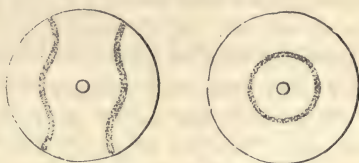


FIG. 221 ($\frac{1}{5}$ real size).

A vase of glass, or a common glass cup with a foot, may be made to sound by drawing a violin bow across the edge at any one point, or by rubbing the edges with a damp finger, applying gentle pressure. In this manner four vibrating portions are always obtained. If the whole is to be divided into six or eight vibrating parts, two points must be touched by the fingers which are respectively $\frac{1}{6}$ th or $\frac{1}{8}$ th of the circumference apart, and the bow must be applied at a point

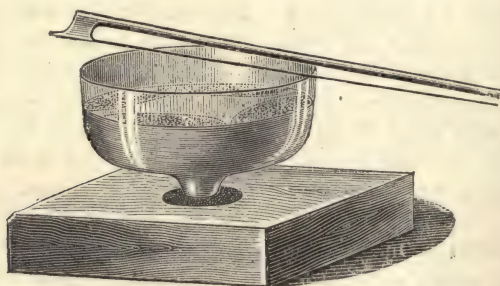


FIG. 222 ($\frac{1}{5}$ real size).

which is $\frac{1}{12}$ th or $\frac{1}{16}$ th of the circumference distant from one of the points at which the fingers are placed. The division into vibrating portions is rendered visible by filling the vase to about two-thirds with water or alcohol. If alcohol be used, the finger must also be moistened with alcohol; if the bow is used instead of the finger the polish of the wood should be protected, by wrapping paper over it against being splashed with the alcohol, which would spoil it.

The vibrations of the glass sides are communicated to the liquid and the surface becomes agitated by delicate waves and divided into four wavy areas, each bounded by an arc of a circle corresponding to the nodal lines of plates. The middle of one arc is always underneath the bow or the finger; if the bow is used the whole figure is stationary, but if the edge be rubbed by the finger the figure move

round with the finger. If somewhat greater pressure be applied by the bow or the finger, the waves become so much agitated that small drops are detached from their crests and a fine rain of spray is formed over the liquid. If the liquid is alcohol the falling drops remain for an instant upon the smooth portion of the surface

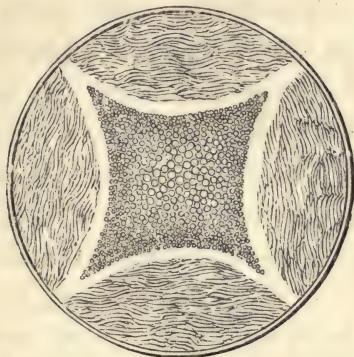


FIG. 223 ($\frac{1}{3}$ real size).

before they disappear in the liquid, and form thus a very pretty picture, fig. 223. A shallow glass shade with a knob, such as is frequently used for domestic purposes, may be used for the experiment. The knob is fitted into a hole suitably bored in a small thick board and fixed with plaster of Paris.

Bodies which have the shape of a rod produce various sounds, according to the different modes in which they are fixed, or set to vibrate. The deepest note of a rod—such as a bar of steel, an iron ruler, or a glass tube—is obtained by holding it at a point which is from $\frac{1}{5}$ th to $\frac{1}{4}$ th of its length distant from either end, and striking with the knuckle of a finger upon the middle or the end

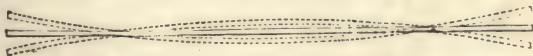


FIG. 224.

of the rod. The rod vibrates in this case as shown in fig. 224, being divided by two nodes into three vibrating segments.

A tuning-fork is a bent rod in which the two nodes are very near to one another. Its mode of vibrating is shown in fig. 225, from which it will be seen that the handle of the fork does not coincide with either of the nodes, but is between them, so that when the fork vibrates, it is moved vigorously up and down and produces a loud note when pressed upon a sounding-board to which it can communicate its motion. In the figure the extent of the motion of the fork is for the sake of clearness, much exaggerated.



FIG. 225.
($\frac{1}{2}$ real size).

Vibrating rods which swing freely produce only very faint notes, on account of their small surface, unless they are rather broad as in the glass-harmonicon, which consists of strips of glass affixed to cords at the node points. To render the tone of a glass tube or steel rod distinctly audible, a thread, from 30 to 50^{cm} long, is tied to it near one end. The other end of the thread is wound round the tip of the forefinger and pressed by the latter into the ear. The freely hanging rod is then sounded.

Besides the transversal vibrations which have been described, rods are capable of performing longitudinal vibrations, in which the particles vibrate in the direction of the length of the rod. The vibrations are produced by holding a rod in the middle and rubbing one half of it, lengthwise, with the moistened finger or with a dam cloth if the rod is of glass; if it is of steel, it should be rubbed with the finger over which some powdered rosin has been sprinkled.

The notes produced by longitudinal vibrations are the higher, the shorter the rods, but are independent of their thickness. The notes produced by transversal vibrations are the higher, the shorter and thicker the rods, and are in general much deeper than those arising from longitudinal vibrations.

The overtones of plates, bells, and rods are not harmonic tones; that is, their numbers of vibrations do not bear the simple ratios to the fundamental note that the overtones of strings do. The overtones do not form consonant combinations with the fundamental note, and hence these bodies are employed only in a very limited degree in music.

Gaseous bodies are capable of performing regular vibratory movements if they are enclosed in vessels with one or more apertures. Tubular vessels are especially adapted for musical purposes. The height of the note produced depends essentially on the length of the vibrating column of air; that is, on the length of the tube. The vibrations of the particles of air resemble those by means of which sound is propagated in air; that is, they are longitudinal vibrations, but the wave produced is termed a *stationary wave* in opposition to a *progressive wave*. Fig. 226 serves to show



Fig. 226.

the kind of motion which gives rise to a stationary wave. In a progressive wave (compare figs. 209 and 210) all particles of air describe equal spaces, but each particle begins and ends its motion an instant later than the preceding one; in a stationary wave, on the other hand, all particles begin and end their motion at the same instant, but the different particles pass through unequal spaces while moving to and fro. Fig. 226 represents a tube open at both ends, and the short vertical lines are supposed to be particles of air, equally distant from one another when the air is at rest; this is the state

represented at *A*, and the air in the tube has in this case clearly the same density as the external air. When the air in the tube is made to vibrate, all particles, except the one in the centre, move at the same instant from their position of rest; the particles on the left of the centre move towards the left, those on the right move towards the right, fig. 226 *B*. The nearer a particle is to the centre, the shorter is the space through which it passes; the largest spaces are described by the particles at either extremity of the tube. The centre of the tube is a node, while each end is the middle of a ventral segment. The density of the air in the tube is at the same time diminished since the particles of air, represented by the lines, recede from one another; but the rarefaction is not equal at the different points: at the ventral segments, where the particles are farthest from their position of equilibrium, the rarefaction is least, but it is greatest at the nodes. This is also easily seen from the figure. When the particles of air have reached their greatest distance from the position of equilibrium, they return, reach again the position of equilibrium, and pass beyond it to the opposite side; that is, the particles of air in that portion of the tube which is on the left move to the right, those in the right move to the left and condensation of air takes place in the whole of the tube. The condensation is likewise greatest at the nodes and least at the ventral segments, as seen in fig. 226 *C*. From the state of condensation the particles of air return again to the position of equilibrium, and the whole movement is repeated in the same successive order as described.

Fig. 227 serves to represent the motion of a stationary wave in the same manner in which fig. 210 represented that of progressive waves. A piece of paper, as described on page 331, is placed with the slit along the dotted line, and the book drawn along underneath it.

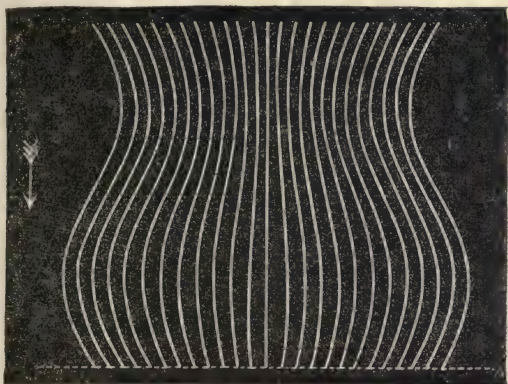


FIG. 227.

In tubes open at one end only, the air performs quite similar vibrations to those in tubes open at both ends. A tube closed at one end behaves exactly like one half of a tube which has twice its length and is open at both ends; the closed end of the former corresponds to the middle of the latter, and the open end corresponds to one of the open ends of a tube twice as long and open at both ends; in other words, at the open end a ventral segment is produced, at the closed end a node is formed. It is evident from this that a tube closed at one end gives out the same note as that produced by a tube which is twice as long and open at both ends.

Vibrations in tubes may be produced in various ways; most easily by resonance. If a tuning-fork is sounded and held across the upper end of a tube the air in which is capable of vibrating at the same rate as the tuning-fork, the note will considerably increase in intensity in

consequence of the vibrations produced in the air in the tube.

For a common (a') tuning fork a tube is required which is either $19\text{cm}\cdot5$ long if closed at one end, or 39cm long if open at both ends. Tubes of about 25mm width are the best for this experiment. A cylindrical jar with a foot, about 25cm high, will serve as a tube closed at one end. Water may be poured into it gradually until the sound of the fork reaches its greatest intensity, that is, until the column of air in the tube has the exact length required for per

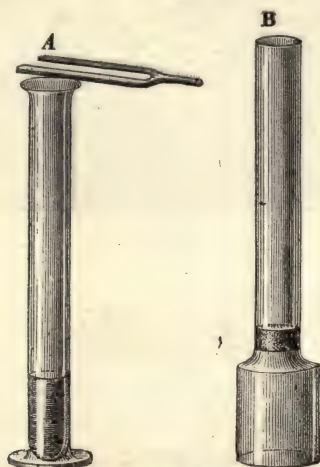


FIG. 228 (*an. proj.* $\frac{1}{5}$ real size).

forming vibrations of equal duration to those of the tuning-fork (fig. 228, A). A lamp cylinder will serve equally well, if a well-fitting cork is introduced from the wider end and pushed inward until the column of air above it has the required length (fig. 228, B). The tubes may also be made by rolling stout paper or thin cardboard round a cylindrical bar of suitable thickness, and fastening the edges with glue: one end may be again closed by a cork, which must, however, be fixed with glue or sealing-wax.

A remarkable method of producing a note in tubes open at both ends consists in allowing a small flame of a gas—hydrogen is the best for the purpose—to burn inside the tube. Such a flame will not burn long in a tube which is closed at one end, because of the impos-

ility of producing the necessary draught, that is, the constant renewal of air required for combustion.

The apparatus for producing notes in this manner has been termed the *chemical harmonicon*. It consists of a tube of glass or of sheet metal, which is best clamped in the retort-holder, and of a small gas-burner, which reaches to some distance into the tube. The burner is a small straight tube, tapering towards the upper end, which has an aperture of 0.5 or 1^{mm}; it is usually a glass tube, drawn to a point, connected by means of an indiarubber tube with gas-pipe, or with an apparatus for making hydrogen, and clamped

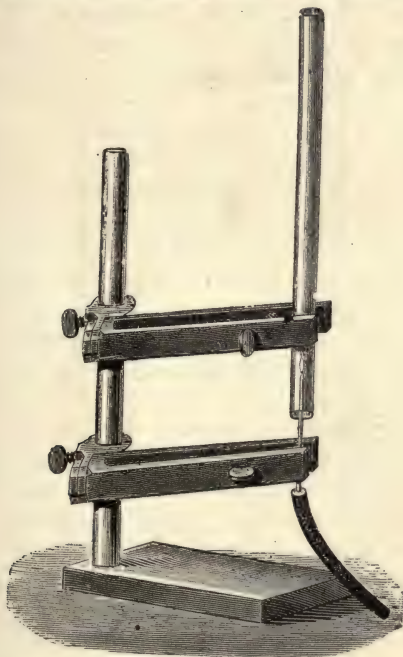


FIG. 229 (*an. proj.* $\frac{1}{8}$ real size).

a second arm attached to the retort-holder. The sounding tube may have a width of from 15 to 30^{mm}, and a length of from 20 to 100^{cm}. The most convenient size of the flame and the most suitable height of the burner in the tube should be ascertained by trial; both are approximately represented in fig. 229. If coal-gas is used, the size of the flame requires more careful regulation than for a hydrogen flame; but even in the latter case it is desirable to have a stop-cock for regulating it, and the apparatus in fig. 156 is therefore preferable to that in fig. 154.

The jet of hydrogen should under no circumstances be ignited until the purity of the gas has been ascertained, for a mixture of air and hydrogen explodes when lighted, and the apparatus may be shattered to pieces. A sufficient quantity of the gas should therefore be allowed to escape, and then a glass tube about 10^{cm} long is attached to the indiarubber tube, which serves for connecting the jet with the apparatus for generating the gas. A quantity of gas is now permitted to enter a test tube in the manner described on page 317. The tube filled with the gas is closed with the thumb and lifted from the water; the thumb is then withdrawn, and a burning match is held close to the mouth. A faint explosion will be heard because some air mixes with the hydrogen at the mouth of the tube, but the greater portion of the gas should *burn slowly and quietly with a bluish flame which is scarcely visible*: if the gas is mixed with atmospheric air, it burns with a whistling sound or with a sound like a short bark or pop. The gas should never be lighted unless the above test has been applied; even if the apparatus has stood for some time filled with the gas, and the gas has been tested on before, it should be tested again before using it.

When the gas is free from air, the indiarubber tube is attached to the jet tube, the gas ignited and the glass tube placed over it. As soon as it has the proper position, the tube emits a loud note.

The vibration of the air in the tube causes, as has been explained, a rapid increase and decrease of the density and consequently of the pressure. These variations of the pressure interfere with the steady efflux of the gas from the jet; it issues in many successive jerks, and instead of a quietly burning flame we have a series of separate combustions, each of which causes the air to be heated, and consequently to be expanded: each, therefore, adds a new impulse for the continuation of the movement. The successive combustions succeed one another so rapidly that the second is seen before the impression produced upon the eye by the first has disappeared, and consequently the flame appears to be continuous; but in reality it is a series of successively ignited jets, as will be shown hereafter. The continuance of the vibrations, after they have been once produced, is thus easily explained by the alternate expansion and condensation of the air produced by the intermittent combustion of the gas. But the first production of these vibrations must have some other cause, and the whole phenomenon is not yet sufficiently accounted for. It is possible that the draught produced by the flame has a share in the production of the sound.

When the tube is removed, after the most suitable position for the production of the note has been determined, and the apparatus

again put together so as to give to the tube a position which is near to, but not exactly, its proper one, a long time will often elapse before it begins to sound again. But if the notes of the gamut are loudly sung or whistled in the vicinity of the tube, it will sound immediately, when the note is sounded which the tube itself produces; this is because the air in the tube is thrown into vibration, and thus it produces the intermittent flow of the gas. Conversely, if the flame has not the most suitable position, the note given out by the tube may be silenced immediately by sounding strongly a note which is a little higher or lower than the note of the tube; here sonorous waves enter the tube in somewhat slower or quicker succession than those which are produced within: the regular interruption of the flow of the gas from the jet is interfered with, and the production of sound ceases.

The most usual mode of producing vibrations of columns of air in tubes, and the one which is chiefly used in musical instruments, is to blow air across the aperture of a tube. With the help of an indiarubber tube,

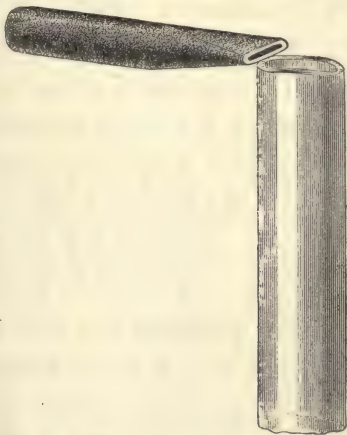


FIG. 230 (*an. proj.* $\frac{2}{3}$ *real size*).

the end of which is slightly compressed with the fingers so as to obtain a narrow, elongated aperture, notes may be produced from tubes which are either open at both ends or at one only, and also from various hollow vessels (bottles, &c.).

Fig. 230 shows the relative position of the indiarubber tube and glass tube (the fingers which hold the rubber tube are left out). To save the trouble of pressing the end every time with the fingers, thin wire softened by annealing may be wrapped round the tube and then pressed together into the required shape. The end of the tube is kept in shape by the wire.

The flute is a tube open at both ends, one aperture however, being not quite at the end, but near it and at the side. A current of air is directed by the lips over this lateral opening. The so-called 'flue'-pipes of an organ, and common whistles, are tubes which have also a lateral aperture at one end, and are either open or closed at the other end; a current of air is directed through a narrow slit, and strikes the opposite sharp edge of the aperture or 'mouth' of the instrument. Fig. 231 shows the construction of a wooden organ pipe, which differs very little from that of a common whistle. The figure shows a section through the length of the tube, which is square; organ-pipes of metal are round, and flattened only near the mouth.



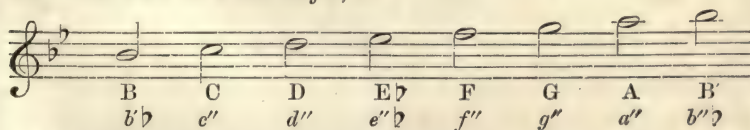
Fig. 231
(an. proj.
 $\frac{1}{3}$ real size).

The rate at which the longitudinal vibrations of the air in tubes take place, and hence the pitch of the notes produced, depends, like the similar vibrations of rods, principally upon the length of the vibrating mass: the number of vibrations is in the inverse ratio of the length. Four tubes which are to produce a perfect major chord, in which the vibrations are in the ratios $1: \frac{5}{4}: \frac{3}{2}: 2$, must have their lengths in the ratios $1: \frac{4}{5}: \frac{2}{3}: \frac{1}{2}$ —for example, they may be respectively 30, 24, 20,

and 15^{cm} long. We have seen that a tube closed at one end gives out the same note as that produced by a tube of double the length and open at both ends ; the number of vibrations in the former is therefore one half of the number of vibrations of a tube of the same length, but open at both ends. In other words, the note produced by a tube closed at one end is an octave below the note produced by a tube open at both ends, if both tubes have the same length.

If the student cannot procure proper instruments for these experiments, tubes made of stout paper or very thin cardboard may be used. They do not emit musical notes, but allow of a sufficiently distinct determination of the pitch of their sound for confirming the law stated above, on the relation between the length of the tube and the number of vibrations.

Strips of paper or cardboard, of the length stated (15 to 30^{cm}) and from 7 to 10^{cm} broad, are rolled round a cylindrical rod or stout glass tube, so as to bend them into cylindrical shape, and the long edges are then glued together. If such a tube, after being dried, is allowed to fall horizontally upon a table, it emits a sound which by itself is not very distinct ; but if the four tubes are dropped in rapid succession, the gradation in the pitch of the four notes which constitute the chord will be distinctly heard. Let another tube be made out of a strip 16^{cm} long and 10^{cm} broad, and one end be closed by a circular piece of cork, 1^{cm} thick, which is fixed with glue into the end, leaving inside the tube a clear length of 15^{cm}. If the tube be held inclined, the closed end resting on the table, and allowed to fall, the sound will be found to have the same pitch as that of the tube 30^{cm} long which is open at both ends. Instead of letting the tubes fall, they may also be placed upon some soft support (a piece of cloth), and sounded by knocking them gently with a pencil. If a series of eight tubes be made, of the respective lengths, 36, 32, 28·8, 27, 24, 21·6, 19·2, and 18^{cm}, they will sound the whole scale in B flat major,



and it will be possible to play whole airs upon the tubes.

The overtones of columns of air in tubes are 'harmonic;' that is, their numbers of vibrations are whole multiples of the vibrations of the fundamental note. Tubes which are open at both ends are capable of giving out the whole series of overtones, like vibrating cords (compare page 362); tubes closed at one end can only give out those overtones of which the numbers of vibrations are *odd* multiples of their fundamental note; thus, for *c* as fundamental note, the overtones *g*, *e'*, *b'b*, *d''*. Between the sounds of two organ-pipes, one open at the end and the other closed (or 'stopped'), there is a difference similar to that between the sounds of two cords, of which one is plucked near the end, and the other near the middle: the sound in the latter case is weaker and more nasal. In general, the overtones of tubes are fainter than those of strings; the sound of tubes is therefore always much softer than that of strings. Organ-pipes, especially when narrow compared with their length, give out overtones without the fundamental note if they are blown with considerably greater force than is required for the production of the fundamental note; in open pipes the octave, twelfth, and second octave may in this manner easily be obtained, and in stopped pipes the twelfth, and the third above the second octave.

In fig. 232 the manner in which the air moves in tubes is pointed out by small arrows; the perpendicular lines indicate the positions of nodes. In tubes closed at one end there must always be a node at the closed end. *A* and *B* exhibit the motion of air for the production of the fundamental note; *C* to *H* show the production of the overtones.

The rigid parts of the tube act in those vibrations of

columns of air which have been hitherto considered solely as boundaries of the vibrating mass of air; they do not take any part in the production of the notes, and do not vibrate at all, or are only agitated to a small extent by the violent motion of the air within. If the finger be placed upon a large sounding organ-pipe, its vibration will be felt, but the pipe may be firmly held without producing any modification of the note given out, while, on the other hand, solid bodies which produce sound by

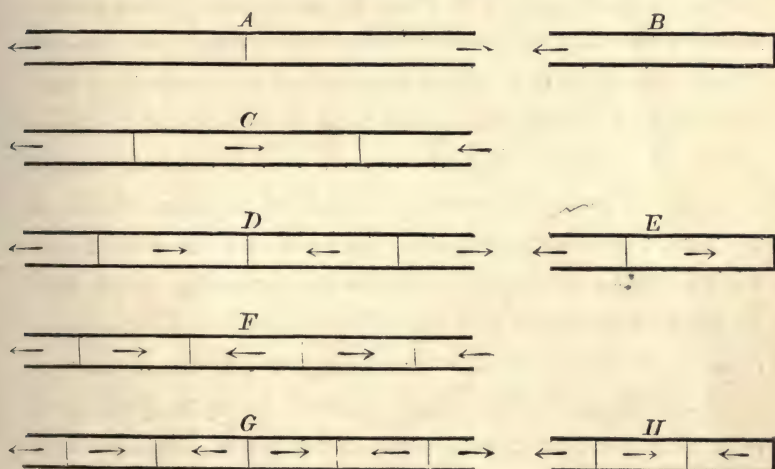


FIG. 232.

their own vibrations are immediately silenced when touched.

An essentially different mode of producing vibrations of columns of air is that by means of solid but flexible bodies which are made to vibrate at the same time as the air. If a current of air is blown between two flexible bodies which are in moderately firm contact with one another, as for instance between the closed lips, or between the fingers of the hand placed flat upon the

mouth, or between the lips and a leaf held close before them, a sound may be produced which is caused in a similar manner to that of the siren. The compressed air forces its way out by slightly pushing aside the two bodies; which, in consequence of their elasticity, instantly return to their original position, and are immediately afterwards again pushed back by the continuous current of air; the same movement is repeated many times in rapid succession; a series of impulses is thus given to the air, and a note is produced. The movement of the flexible bodies is, however, rather irregular: the impulses do not follow each other at precisely equal intervals of time; hence the note is impure, of variable pitch, and not pleasing to the ear. But if the soft bodies are placed so as to close one end of a tube, which is open at the other end, and air is blown between them with suitable force, the column of air in the tube will be made to vibrate, and its vibrations will determine the rate of vibration of the flexible parts; their motion is thus made perfectly regular, and a pure, full, and powerful tone is given out. The pitch of this tone naturally depends, as in other tubes, upon the length of the vibrating column of air.

A pure and strong note may be produced, after a few trials, by means of a tube of cardboard or, still better, of glass, 2^{cm} wide and from 40 to 100^{cm} long, which is held close to the lips, while a current of air is forced from the mouth through the tube, the lips being pressed together with moderate firmness. When the lips are more compressed and the tube is rather long, while the air is blown more vigorously through it, the twelfth will be obtained besides the fundamental note,

and numerous other overtones, all odd numbered, may be obtained by means of a very long but narrow (1 or 1^{cm}·5) tube.

It is thus that notes are produced in all wind instruments, except the flute. In brass instruments the lips form the soft vibrating parts; in wood instruments, for example in the clarinet, the air is forced through 'reeds,' formed of two thin elastic plates of wood or cane. The difference in pitch of the various notes produced by such instruments is obtained by various modes. The tube being in most of them, especially in brass instruments, very long, it is possible, by altering the position of the lips and the manner of blowing, to produce a whole series of different overtones. The length of the tube may also be varied by different means. Thus in the *trombone* one part of the tube slides within the other; the performer can thus alter the length of the tube at will, and therefore produce higher or lower sounds. In the *cornet-à-piston* the tube forms several convolutions, and by means of pistons placed at different distances the communication with other parts of the tube may be cut off, and thus the length of the column of air altered while the instrument is played. In other cases there are holes at different distances in the side of the instrument, which may be closed or opened. In such an instrument the whole length of the column of air within vibrates only when all lateral holes are closed. When one of the holes is opened, a ventral segment is produced in the corresponding layer of air, which modifies the distribution of nodes and ventral segments throughout the interior, and thus alters the note.

The soft elastic plates of wood or cane, or 'reeds,'

used in these instruments differ essentially in their mode of action from the strong elastic tongues applied in other instruments, for instance in the *concertina*, the *accordion*, the *harmonium*, or the *reed-pipes* of the organ. These metal tongues are thin, long, narrow rectangular plates of hardened brass or german-silver, fixed by their thicker ends upon a plate of metal, usually of zinc, so as nearly to close a rectangular slit in the plate. In fig. 233, A

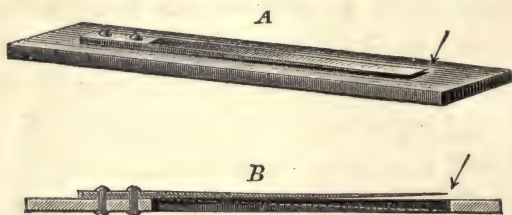


FIG. 233 (A, an. proj.; A and B, real size).

represents the exterior, *B* a section of such a tongue. The plate with the tongue fixed upon it is called a 'reed;' it is fastened so as to form one side of a small box into which air can be forced through an opening; that side of the plate upon which the tongue is fixed is turned towards the inside of the box, and, as the current of air escapes from it, it presses the tongue in the direction of the small arrow into the slit of the plate, into the position indicated by the dotted line; the slit is thus for an instant more completely closed than before, and the current of air almost entirely interrupted. Consequently the elasticity of the tongue immediately causes it to return to its first position; a passage is thus again opened for the air; the current is re-established and carries the tongue with it, as before, so as again to obstruct its own path; the tongue then springs back once more, and so the action is continually

repeated as long as air is forced into the box. If the tongue is simply bent down with the finger and let go, it will vibrate to and fro, but no sound, or only a faint trace of a sound, will be heard; hence the sound is solely due to the regular periodic interruption of the current of air, in the same way as in the siren. But the pitch of the note does not depend, as in the case of more flexible reeds, upon the length of the vibrating column of air in front of the reed; it depends, in the case of metallic reeds, upon their length, thickness, and shape; for the velocity with which the vibrations take place depends upon these circumstances precisely as in the case of a vibrating rod or a tuning-fork: a tongue of a definite form will perform a definite number of vibrations in a given time. The whole series of harmonic overtones, especially those which are odd numbered, are contained in great strength in the sound produced by such a metallic reed, but it is not possible, as was the case with the various contrivances hitherto described, to produce overtones by means of a metal reed without producing the fundamental note at the same time. Mathematical reasoning alone can show how it is possible that a note which is produced by a series of single impulses may contain overtones besides the fundamental tone.

Wind instruments with soft vibrating parts are usually called *mouth instruments*; such are a common whistle, a flageolet, &c. Instruments with metal tongues, such as those just described, are termed *reed instruments*. The simplest form of a 'reed,' or metal tongue, is seen in the jew's harp; it is also applied in the oboe, the bassoon, the children's trumpet, &c.

* The sound of a reed instrument is, in consequence of the great number of overtones, rather harsh. In the case of the reed pipes of the organ, the character of the sound is modified to an important degree by the vibrations of the air in the open part of the pipe above the reed. The rate of vibration of the air contained in this part of the pipe depends upon its size and shape, and if this rate agrees with that of the fundamental or any of the higher harmonic tones of the reed, the air is thrown into powerful sympathetic vibrations, and the corresponding tone is thus greatly strengthened in comparison with the other tones of the sound.

36. *The Organ of Voice. Vowel Sounds. Flame-Manometer.*—The organs by means of which the human voice is produced resemble a reed organ-pipe—with the essential difference that a metal tongue produces only one note of a definite pitch, while the tones of the human voice may be varied in pitch at the will of the speaker. The upper end of the windpipe is formed by a short tubular box, called the *larynx*, the framework of which is formed by a number of cartilages more or less moveable on each other and connected together by joints, membranes, and muscles. Across the middle of the larynx is a transverse partition, formed by two folds of membrane stretching from either side but not quite meeting in the middle line. They thus leave, in the middle line, a chink or slit, running from the front to the back, called the *glottis*. The two edges of this slit are sharp and, so to speak, clean cut. They are also strengthened by a quantity of elastic tissue, the fibres of which are disposed lengthways in them. These sharp free edges of the glottis are the

so-called *vocal chords* or *vocal ligaments*. During respiration the vocal chords are quite slack, the glottis is rather wide, and a current of air passing through it produces no sound; but in speaking and singing the vocal ligaments are tightened by the action of the muscles of the larynx, their edges are close together, and the air, as in a reed-pipe, is compelled to force a passage for itself between them; they are thus made to vibrate, and a periodically interrupted current of air, that is, a series of impulses, is produced. Although the vocal chords are soft, indeed much softer than the elastic plates of mouth instruments, their action, especially when they are stretched, is rather that of metal tongues than that of soft plates, for their elasticity, and consequently the pitch of the notes produced, does not depend on the length of the aerial column before them (that in the cavity of the mouth), but upon their tension: the note will be high or low according as the vocal chords are tightened or relaxed. If the larynx be removed from the body and air be blown through it by a pair of bellows, sound is produced, and the pitch may be varied by varying the tension of the vocal chords. The quality of the sound emitted resembles that of a reed pipe, but the human voice receives its peculiar quality from a variety of accidental circumstances: it depends upon the formation of each particular larynx, the primitive length of its vocal chords, their elasticity, the amount of resonance of the surrounding parts, and so on.

Speech is voice modulated by the throat, tongue, and lips, and the modulation is effected by changing the form of the cavity of the mouth and nose by the action

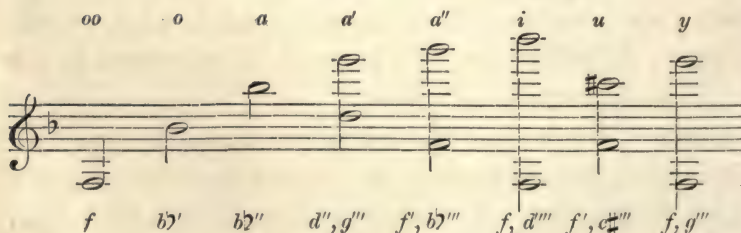
of the muscles which move the walls of those parts. The characteristics of the sounds called *vowel sounds* are especially remarkable and important. Thus if the pure vowel sounds

E (as in *he*); *A* (as in *hay*); *A* (as in *ah*);
O (as in *or*); *O'* (as in *oh*); *OO* (as in *cool*);

are pronounced successively, it will be found that they may be all formed out of the sound produced by a continuous expiration, the mouth being kept open, but the form of its aperture, and the extent to which the lips are thrust out or drawn in so as to lengthen or shorten the distance of the orifice from the larynx, being changed for each vowel. A definite position of the mouth is thus required for each vowel, and the cavity of the mouth has the office of strengthening in each case one or several definite tones. Thus the following vowel sounds correspond to the musical notes placed opposite them:—

oo (as in *cool*) corresponds to *f*.

<i>o</i> (as in <i>no</i>)	„	„ <i>b♭'</i> .
<i>a</i> (as in <i>far</i>)	„	„ <i>b♭''</i> .
<i>a'</i> (as in <i>fat</i>)	„	„ <i>d'', g'''</i> .
<i>a''</i> (as in <i>fate</i>)	„	„ <i>f', b♭'''</i> .
<i>i</i> (as in <i>field</i>)	„	„ <i>f, d'''</i> .
<i>u</i> (as in <i>fur</i>)	„	„ <i>f', c♯'''</i> .
<i>y</i> (as in <i>truly</i>)	„	„ <i>f, g'''</i> .



Whatever the pitch of the note produced by the larynx, and whatever difference may exist among the persons uttering these vowels, the sounds produced by the cavity of the mouth remain the same. In whispering, these sounds are produced alone, accompanied only by the sound made by the air when it leaves the cavity of the mouth; in whispering there is a kind of voice produced by the vibrations of the muscular walls of the lips, which thus replace the vocal chords. If tuning-forks which sound the above notes are successively placed before the mouth, and the particular formation is given to it which is required for the production of the corresponding vowel sound, the sound of the tuning-fork will be very considerably increased by the resonance from the cavity of the mouth.

The acquisition of a whole series of tuning-forks for these experiments is rather expensive. It is, however, easy to prepare a fork which gives out $b\gamma'$, the note corresponding to o , by filing away a small piece from the prongs of a common a' tuning-fork, and thus raising its pitch. The fork should be clamped for this purpose in the vice, between lead or copper cheeks, so as to project but very little. After a few rasps with not too coarse a file the fork should be again taken out, and its pitch examined. If the student cannot rely upon his ear, the fork should be compared with the note $b\gamma'$ of a correctly tuned piano; this is done by striking the fork, placing the stem upon the sounding-box, and striking the key $b\gamma'$ moderately at the same time and keeping it pressed down: as long as both notes are not in unison beats will be heard.

In order to be able to hold the fork as closely as possible before the mouth without touching the lips and thus stopping the vibrations, it is best to perform the experiment before a looking-glass. The fork is held horizontal, the prongs over one another, the free ends before the mouth. It is somewhat difficult at first to form the mouth into the proper shape for each vowel without really producing the vowel from the larynx; it is therefore advisable to whisper the vowels one after the other; as soon as the vowel o is whispered, the sound of the fork will be considerably strengthened;

it will be recognised even if the series of vowels are successively pronounced in a low voice, whereby it may be proved that the sound of the cavity of the mouth remains the same, whatever the pitch of the larynx-sound proper.

The vowel sounds of the cavity of the mouth may be also rendered audible by blowing a broad current of air across the lips or upon the sharp edges of the teeth, that is, in the same manner as the notes of a column of air in a tube. For this experiment, however, much practice is required, and the bellows used for it must be capable of producing a lasting and invariable current of air.

Certain *consonants* also may be produced without interrupting the current of expired air, by modification of the form of the throat and mouth. Thus the aspirate *H* is the result of a little extra expiratory force—a sort of incipient cough. *S* and *Z*, *Sh* and *J*, *Th*, *L*, *R*, *F*, *V*, may likewise all be produced by continuous currents of air forced through the mouth, the shape of the cavity of which is peculiarly modified by the tongue and lips. The sounds *M* and *N* can only be formed by blocking the current of air which passes through the mouth, while free passage is left through the nose. For *M*, the mouth is shut by the lips; for *N*, by the application of the tongue to the palate. The other consonantal sounds of the English language are produced by shutting the passage through both nose and mouth; and, as it were, forcing the expiratory vocal current through the obstacle furnished by the latter, the character of which obstacle gives each consonant its peculiarity. Thus, in producing the consonants *B* and *P*, the mouth is shut by the lips, which are then forced open in this explosive manner.

In *T* and *D*, the mouth passage is suddenly barred by the application of the point of the tongue to the teeth, or to the front part of the palate; while in *K* and *G* (hard, as in *go*), the middle and back of the tongue are similarly forced against the back part of the palate.

An interesting contrivance for rendering *visible* the difference of the vowel sounds, and also for other acoustic experiments, is the *gas-flame manometer*. The

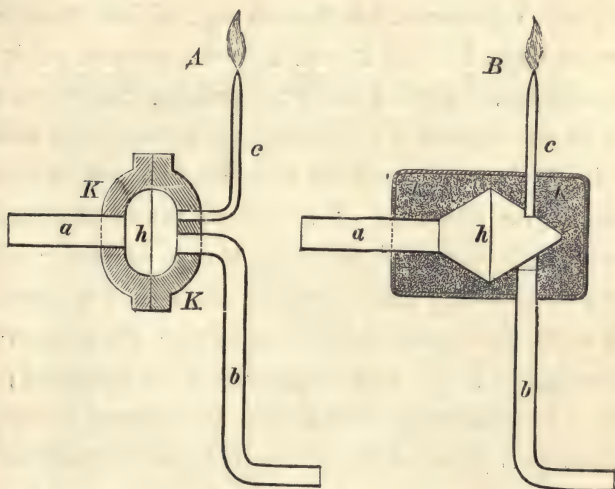


FIG. 234 ($\frac{1}{2}$ real size).

most essential part of the apparatus is a capsule, *KK*, fig. 234, which is composed of two parts. Its interior is divided into two cavities, separated by a very thin membrane, *h*; into one leads a tube, *a*, to which an india-rubber tube may be attached for conveying sound into the interior; into the other cavity illuminating gas can be conducted by the pipe *b*; it issues again from the small tube *c*, and may be ignited at the extremity of the latter tube. When sonorous vibrations are pass-

ing through the india-rubber tube and the tube *a* into the anterior portion of the capsule, the thin membrane is made to vibrate, these vibrations are communicated to the gas in the posterior part of the capsule, and the gas issues not in a steady flow, but in a series of impulses. Instead of a quietly burning single flame, we obtain a succession of little flames similar to the flame of the chemical harmonicon. Each little flame corresponds to a sonorous vibration, in which the condensed wave presses the membrane, which thus compresses the gas behind it and drives a portion of it out of the burner. At the next rarefaction the membrane moves in the opposite direction, the pressure of the gas is diminished, and its efflux either ceases for an instant altogether or becomes at any rate much diminished. If the flame is watched steadily, the eyes being rather close to it, the only effect observable is that it lengthens out in consequence of the action of the sonorous vibrations produced by the note which is sounded: the sonorous impulses expel the gas with more force and therefore to a greater height. But the appearance of the flame is very different, if it is observed at a distance of from 1·5 to 3^m, while at the same time the head is moved moderately quickly from side to side, to and fro. In this case the image of the flame impinges upon constantly varying portions of the eye, and if a narrow flame is burning steadily, it appears as a broad band, while a flame acted on by sonorous vibrations, by means of our apparatus, appears as a series of little flames placed side by side.

The motion of the head prevents a close examination of the appearance; besides, it is inconvenient and

causes often headache. It answers better to use an opera-glass, moving it from side to side before the eyes, while the head is kept in a steady position.

The best mode of observing the flame is by means of a moving mirror. A square box, the sides of which are made of looking-glass, made to rotate in the vicinity of the flame with moderate velocity, enables a great number of persons to observe the flame very conveniently.

The image of an object before a mirror is always seen

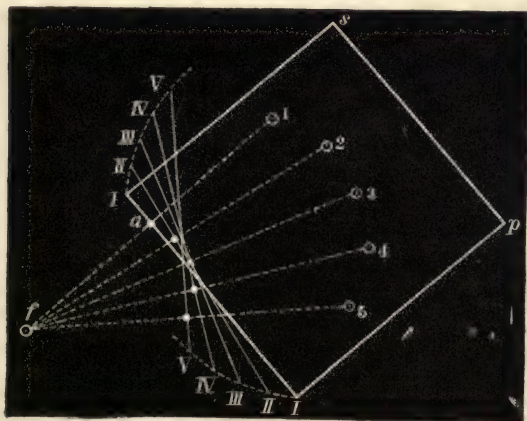


FIG. 235 ($\frac{1}{4}$ real size).

as far behind the mirror as the object is before the mirror, and it appears upon the straight line which is drawn from the object perpendicular to the surface of the mirror (see further on, Art. 39). In fig. 235, let I I s p represent the box, with its sides of looking-glass as seen from above at any instant; and let II II, III III, IV IV, V V, represent the changed positions which the side I I occupies in successive instants of time, while the box is rotating; let *f* be the flame. If

a line fa be drawn from f , perpendicular upon II , and produced so that its production is equal to fa , the place is found where the image is formed; in the figure this place is marked by the number 1. The image will, however, appear only at 1 as long as the mirror has the position II ; when this side of the mirror arrives at the position $II' II'$, the image of the flame is found, by a similar construction, to be at the place marked by number 2; when the side II is at $III III'$, the image of the flame is at 3, and so on. While the side of the

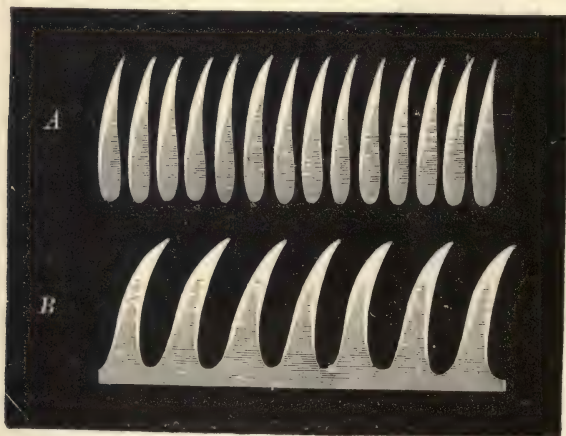


FIG. 236.

mirror turns from the position II to the position $V V$, the image moves successively from 1 to 2, 3, 4 and 5. If the flame burns steadily, it will appear in the mirror as a narrow band between 1 and 5; but if it consists of a series of single rapidly succeeding ignitions, a series of single images of the flames will appear side by side in the mirror, as in fig. 236, *A*. The distance of the individual images from one another depends upon the velocity with which the box rotates and upon the pitch

of the note, of which the sonorous vibrations are acting upon the membrane in the capsule of the apparatus. The quicker the apparatus is turned the greater is the space through which the image travels in a given time, and the greater is therefore the distance between the images of the successive flames which correspond to the successive vibrations. Again, if the box is turned constantly with the same velocity, there will be less images of flames within a given space if there are fewer vibrations in a given time; in other words, the images are the farther apart from one another the deeper the note which acts upon the issuing gas. Fig. 236, *B*, shows the series of images which corresponds to a note which is one octave lower than the note which produces the series of images at *A*.

The later in time a flame is produced the more its image appears to have moved laterally; since the upper portions of the flame are produced earlier than the lower, the image of the upper portions moves onward while that of those later produced appears to lag behind; hence the upper portions of the flame appear curved, with points which are turned towards the direction in which the images move. If the successive impulses which cause the interruption of the flow of gas are not very rapid nor strong, the efflux of gas never ceases altogether, but is only diminished, and as a consequence the images of the successive flames form a connected band at their lowest portions, as shown in fig. 236, *B*.

The two saucer-shaped halves of the wooden capsule should be made by a turner of hard wood; their section may be seen from fig. 234, *A*. After boring the holes for the tubes, a thin layer of glue is spread over the rim of one of the saucers, and gold-beater's skin is

stretched across it; the second half of the capsule, over the rim of which glue has also been spread previously, is then placed upon the first. The whole is then pressed together moderately in the vice and kept there until dry. The glue along the joint and the projecting portions of the gold-beater's skin are afterwards removed with a sharp knife. The tubes are of glass; their shape and size appear from the figure; the aperture of *c* should be about $0^{\text{mm}}\cdot4$. The vertical portions of the tube *b* may be clamped in the retort-stand. It is advisable to varnish the capsule outside several times with asphaltum varnish, until the surface has a glossy appearance when dry; this is done to render the wood gas-tight, which unvarnished wood is not.

For the capsule a large cork may be substituted. It is cut across the middle, the necessary holes are bored in it for the tubes, and a conical cavity is cut into each half with a sharp penknife, as shown in fig. 234, *B*. Large corks are never quite air-tight; the whole of the outside should therefore be covered with a layer of sealing-wax 1 or 2^{mm} thick; this is done after the two halves have been glued together and the whole is perfectly dry.

For the reflecting box four square pieces of common looking-glass must be procured, each 14^{cm} long and 12^{cm} wide; the bottom of the box is made of a square of very stout pasteboard, each side being 14^{cm} long. In the middle of the square a hole is made, 5^{mm} wide, for attaching it by means of a screw to the disc of the whirling-table. The upper side of the box is left open so that the arm may conveniently reach the screw. The sides of the box are first joined together by strips of paper, $1\cdot5$ or 2^{cm} broad, over which moderately thick glue is spread in a very thin layer; when the glue is dry, the edges are fastened together by pieces of black linen tape, $2^{\text{cm}}\cdot5$ wide, using for the purpose rather thick glue. Four pieces of the length required are first placed along the vertical edges. Two pieces are then placed all round the box, one round the upper, the other round the lower edge, and the length of these pieces should be such that the ends may overlap one another for 2 or 3^{cm} . This is the best way of protecting the box against the action of the centrifugal force which tends to separate the sides from one another. Of these two pieces of tape half of the width is glued all round, above and below, to the outside of the box; the other half is turned inside at the upper edge, and folded round upon the bottom of the box at the lower edge. At the four lower corners, the tape must be cut half-way across, so that it can be placed flat upon the bottom without making folds.

The flame should be about 10 or 15^{cm} distant from the box. To protect the flame against the current of air which arises when the box is turned, a glass tube is placed over it. The narrower portion

of a common lamp cylinder, separated by pastille from the wider part, may be used for this purpose; the tube should not be wider or longer, otherwise it may begin to sound like a chemical harmonicon.

The images of the flame are somewhat faint; the experiments should therefore be performed during the evening in a dark room. The flame is best fed by common gas; if gas is not to be had, hydrogen must be used. The flame of burning hydrogen is so faint, that the images could scarcely be seen even in a dark room. It is therefore necessary to pass the hydrogen, which is made by means of the apparatus shown in fig. 156, (see p. 226) through the stopcock *h* of that apparatus by means of an india-rubber tube into a small jar, arranged as in the apparatus shown in fig. 154, the cotton wool in which has been previously moistened with petroleum-spirit. The vapour of this volatile liquid mixes with the hydrogen which passes through the jar, and renders it capable of burning with a strongly luminous flame. If needful the apparatus, fig. 154, may be used for the whole arrangement, including the generation of hydrogen, simply moistening the cotton wool in the small jar by the petroleum-spirit. But, in that case, it often happens either that the flame is too small, as when too little sulphuric acid is poured into the generating bottle, or that it is too large, when too much of the acid has been used, in which latter case the liquid is apt to rise in the funnel tube and to run over.

The handle of the whirling table is turned quite slowly, so that the box may rotate about once in a second. Instead of working the handle, the box may be turned by the finger, placing the tip upon one of the upper corners.

The india-rubber tube which is attached to the tube *a* should have a width, if possible, of 8^{mm}, at any rate of not less than 6^{mm}; its length may be from 0.3 to 1^m. A small funnel is inserted into the free end, and notes are sung or whistled into it; or the end of the tube may be simply placed lightly between the teeth, without applying any pressure, and the notes may be sung, the mouth being half open, or the mouth may be closed and the note hummed into the tube.

The rotating mirror-box may also be used for investigating the flame of the chemical harmonicon, which gives also a series of images side by side.

The appearance of the images of the flame, shown in fig. 236, is that produced by the action upon the flame of a simple tone, that is, one not accompanied by per-

ceptible overtones. This appearance is obtained by humming a note into the tube, or by singing or speaking into it the vowel-sound *OO* (as in *cool*). If the gamut is sung in this vowel-sound, beginning with the lowest note of the scale, and turning the box at the same time as uniformly as possible, the images will be seen to approach more and more closely to one another. Although the note *f* is sounded by the cavity of the mouth when *OO* is sung, the effect of it is too weak to exert any perceptible influence upon the flame.

It is different when *O* (as in *oh*) is sung, for in this case the note *bb'* is sounded by the cavity of the mouth while *O* is sounded by the larynx, and the former note influences the flame in some measure; hence the appearance of the images is different. If the pitch in which the vowel is sung is varied, the images not only vary their relative distance, but their whole appearance is changed. The reason of this is that only one note, viz., that produced by the larynx, varies in pitch, while that produced by the cavity of the mouth remains unaltered throughout; in other words, the images, or rather tongues of flame, which correspond to the larynx-sound, alter the relative distances between their points when the pitch changes, while the points of the images which are produced by the cavity of the mouth sounding *bb'* maintain throughout the same distances from one another. The image becomes most instructive if *O* is sung on the note *bb*



In that case the larynx-sound is just one octave

lower than the accompanying sound of the mouth-cavity, or one vibration of the former corresponds to two vibrations of the latter. The larynx-sound alone would then produce a series of images like fig. 236 *B*, the sound of the mouth-cavity alone a series like fig. 236 *A*. But together they give images like fig. 237 *O*, which may be considered as a combination of the two series of images in fig. 236; every second image in *A*, fig. 236, coincides with one of *B* in the same figure and produces a larger flame, while between these enlarged flames, which are due to the sum of the actions of the single flames, there is a series of smaller flames which owe their existence exclusively to the higher note produced simultaneously by the cavity of the mouth.

If the vowel *A* (as in *ah*) is sung on the note *b♭*, the images present the appearance of *A* in fig. 237. The

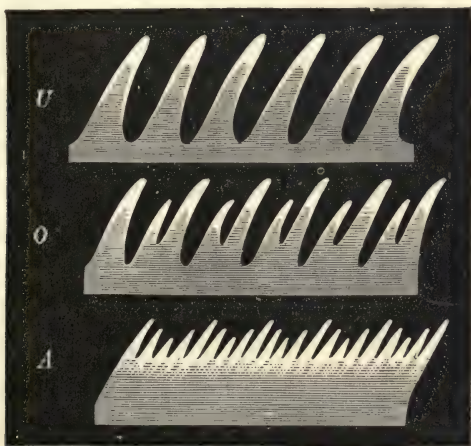


FIG. 237 ($\frac{2}{3}$ real size).

larynx-sound of the vowel *A* (*b♭''*) is two octaves higher than *b♭*; four vibrations of the sound of the mouth-

cavity correspond, therefore, to one of the larynx-sound: that is, every fourth image of the former coincides with one of the latter, or every fourth tongue is longer than the three intermediate ones.

The images produced by *A* (as in *fate*), *I*, and the complex vowel-sounds of the diphthongs are again different from those which have been described; their images are more complicated and not so intelligible as those produced by *OO*, *O*, and *A*, because in the former the larynx-sound is accompanied by *two* sounds which influence the form of the image. Hence the series does not consist of distinct and separate tongues of flame, but of peaks and hollows which render the outline of the whole somewhat indistinct.

37. *Beats. Concord. Discord.*—It has already been mentioned in art. 34 that if two notes which are of nearly the same pitch, so that the ear can perceive little or no difference between them, are sounded together, the intensity of the combined sound is regularly increased and decreased. If the two primary sounds have different intensities, or are produced by different instruments, these variations in intensity of the combined sound, or ‘beats,’ are not so perceptible as when the quality of the two sounds is the same. In the latter case the decrease of sound which takes place between each succeeding beat is sometimes so perfect that a ‘rest’ is produced; that is, the sound ceases altogether for an instant. If the two sounding bodies commence to vibrate precisely at the same instant—thus, for example, if they produce simultaneously a condensation of the air—the effect of each sound taken singly will clearly be increased considerably by the effect of the other, and the sound of both

will be louder than the sound of each when heard alone. But since the rate of vibration is not exactly the same for both sounds, the condensations and rarefactions of air which are produced by the two sonorous bodies cease to take place at the same time. After a short time the condensation produced by one body coincides with the rarefaction produced by the other body, and *vice versâ*; both sounds mutually destroy one another, and this happens when one body has performed just half a vibration more than the other. If one body is in advance of the other by a whole vibration, the condensations and rarefactions again take place at the same time, and the intensity of the sound is again increased; if it is in advance by one vibration and a half, the sound is again destroyed, and so on. The number of times per second that the condensation due to one sound coincides with the condensations or rarefactions respectively due to the other,—that is, the number of beats, or of alternations of loudness and faintness,—is equal to the difference between the numbers of vibrations per second corresponding to the two sounds employed.

That the beats are the more frequent, the greater the difference in pitch of the two notes producing them, may be shown by means of the monochord with two strings. Both strings are first tuned in unison, and then the sound of one is gradually heightened or lowered; beats are thus obtained which follow one another more and more rapidly. In order to obtain slow beats the note of one string may be lowered by weighting the string slightly in the middle without altering the tension; for this purpose a piece of softened copper or brass wire, about 0^{mm}·5 thick and 10^{mm} long, is wound in close turns round the middle of the string, precisely like the strings used for the bass notes of a piano-forte.

To render the beats distinctly perceptible, it is best to pluck both strings simultaneously with the first and second fingers of the right hand, applying the fingers exactly in the middle of the strings, for

by plucking in the middle the even-numbered overtones are excluded. It is owing to the overtones that the sound is never quite silenced between two successive beats, for their numbers of vibrations are multiples by 2, 3, 4, &c., of those of the fundamental note; they produce, therefore, 2, 3, 4, &c. times as many beats. The overtone which is usually most perceptible—the octave of the fundamental note—gives two beats for every one of the latter; hence every alternate beat of the octave coincides with a rest of the fundamental note. A delicate ear is capable of perceiving the octave during the rests of the fundamental note, if the beats are slow and the strings are plucked near the ends. In any case, however, there is never complete silence during the rest of any sound which contains overtones of appreciable intensity. The plucking of the strings in the middle excludes all the even-numbered overtones, as well as the octave, which has a comparatively loud sound; hence the rests are rendered more distinct. They become still more perfect if, instead of strings, tuning-forks are used, for the sounds of these are free from overtones. Two common tuning-forks (a'), as usually purchased, produce almost always fine long beats, because it is very rare that such tuning-forks are precisely equal. They should be sounded by striking them as nearly as possible with equal force, and placing them side by side upon the table or on a sounding-box. If the two tuning-forks should happen to be precisely alike, their notes may be rendered slightly different by placing small india-rubber rings, cut by the scissors from a tube which is about 1^{mm} thick in the sides, upon one of the prongs.

Beats which are so slow that they may be counted are not unpleasant to the ear; but if they succeed so rapidly that twenty or more take place in one second, the sound is rendered harsh and grating. Such rapid beats are the cause of the 'discord' (*dissonance*), which is produced by combinations of certain notes. Two notes which differ by a semitone, for example b' and c'' , produce together a very unpleasant sound; b' makes 495, c'' makes 528 vibrations in one second; hence they produce $528 - 495 = 33$ beats. If B and C be sounded together upon the piano, or better still upon a harmonium, nearly four beats per second may be counted distinctly (the numbers

of their vibrations, $62\frac{1}{6}$ and 66, give $3\frac{1}{6}$); in this case the sound is not less discordant than in the case of b' and c'' , but the discord is due to the rapid beats of the overtones which accompany the deeper notes. The discord produced by c' and b' is as bad as that of b' and c'' , although the two notes, which are distant by nearly an octave from one another, do not themselves give rise to beats; in this case rapid beats are produced by the combination of one fundamental note, viz., b' , with the overtone c'' contained in c' . A similar cause of discord may be traced in other combinations; thus f' and b' sound disagreeable, because the overtone c''' (with $3 \times 352 = 1056$ vibrations) is contained in f' , and c''' together with b'' ($2 \times 495 = 990$ vibrations), which is contained as octave in b' , produce $1056 - 990 = 66$ vibrations per second.

If the relation of those notes is investigated which, when sounded together, produce a pleasing effect, or *concord* (*consonance*), it will be found that neither their fundamental tones nor their overtones give rise to rapid beats. A given note together with its octave produces no beats; together with the fourth or fifth, only weak beats caused by overtones which are pretty high and therefore not very perceptible; somewhat stronger beats originate in the remaining concords (the third and sixth, minor and major): hence the sound is in these cases not quite so agreeable as in the first-mentioned concords.

The existence or absence of strong and rapid beats is thus the sole cause of the dissonance or consonance of notes which are sounded together.

This may be strikingly proved if the student possesses a delicate and well-trained ear. An interval which produces a most un-

pleasant dissonance if sounded upon any common musical instrument, sounds quite agreeable if the notes employed are free from the overtones, and the rapid beats to which they give rise. Such an interval may be taken between the major and minor third. Of three c'' tuning-forks, such as may be easily purchased, one is left unaltered, so as to give a minor third with a common tuning-fork (a'); but one fork is filed down a little at the end until it sounds $c''\sharp$; that is, the major third of a' ; the third fork is also filed down, but only so far that its note may lie half-way between c'' and $c''\sharp$. The last of these forks struck together with a' and placed upon the table gives as good a consonance as a' , c'' , and a' , $c''\sharp$.

OPTICS.

38. *Propagation of Light. Shadow. Photometers.*—The knowledge which we possess of the various objects in the universe is chiefly obtained in consequence of the property of these objects to emit light, and thus to produce an impression upon our eyes. By the sense of touch we can only discriminate those objects which are very near to us; the ear conveys to our mind only impressions of bodies which are sounding, a state which is accidental and comparatively rare; but the eye informs us of the existence of the most distant objects, provided that they are sufficiently luminous,—a condition which is much more common and more lasting than that required for the production of the vibratory movements which render bodies sonorous. A further essential difference between the sensations of light and of sound is that the eye is capable of determining in all cases the direction from which the light proceeds, while the power of the ear to indicate the direction in which the sounding body is situated is very limited and uncertain. On the other hand, the sound produced by a body may reach our ear even if an obstacle be interposed in the path of the sonorous vibrations; sound may, as it were, go round the obstacle. In this respect the eye is inferior as an instrument for gaining information of

surrounding bodies; for light travels solely in a straight line, and if a body which is not transparent is placed in its path, all light is at once stopped.

From a careful examination of certain phenomena of light, it has been ascertained that light, like sound, is a vibratory motion. The vibrations of light differ, however, in many respects from the vibrations of sound. It is not intended in this work to enter into an investigation of these differences; it will be sufficient to state that light does not consist in the vibrations of air or other bodies, but that the vibrations of light are supposed to take place in a medium which pervades space and all bodies in space, and to which the name 'ether' has been given.

All bodies from which light proceeds—that is, all bodies which we can see—are called 'luminous.' Most bodies are luminous in consequence of their reflecting the light which they receive from other bodies, such as the sun, a burning lamp, &c.; but other bodies are 'self-luminous'—for example, the sun, the fixed stars, and any burning or glowing substance.

Light is propagated in every direction from a luminous body with a velocity which is incomparably greater than that of sound. The velocity of light is indeed exceedingly great, for light travels in one second through a distance of nearly 190,000 miles. The measurement of this enormous velocity was first attained by careful observations of the eclipses of Jupiter's satellites.

The planet Jupiter moves round the sun in an orbit the diameter of which is five times as great as the diameter of the Earth's orbit. Jupiter has four satel-

lites, one of which is so near to the planet that during each revolution it passes once through the shadow of the planet, and becomes, for a time, invisible or eclipsed. The period of revolution of this satellite is only about 42h. 28m. 36s.; these eclipses, therefore, take place very frequently, and they may be well observed by means of a tolerably good telescope. Since the motion of the satellite is very uniform, the intervals between the successive eclipses should be equal; but, as observed from the Earth, these intervals seem to be greater at one time than at another.

The Earth moves in its orbit with a greater velocity than Jupiter. Let ab , in fig. 238, represent that portion of the orbit which

the Earth traverses while Jupiter moves from a_1 to b_1 . It will easily be seen that the Earth during this time approaches Jupiter. When the Earth arrives at c , Jupiter has moved to c_1 , and while the Earth passes from c to d , Jupiter moves from c_1 to d_1 , and the Earth recedes from Jupiter.

When the Earth is at a , and Jupiter at a_1 , their

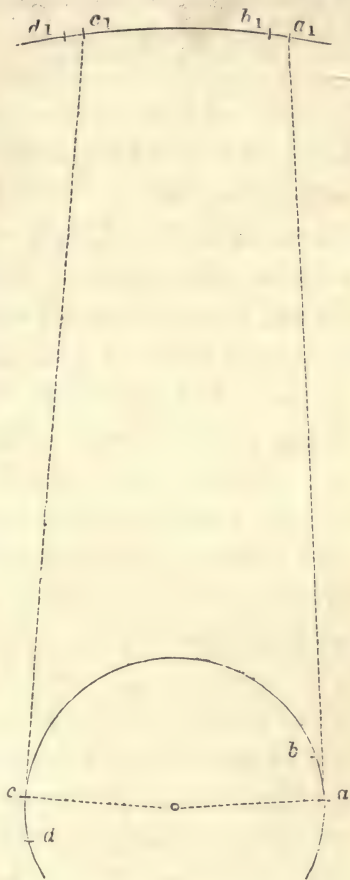


FIG. 238.

distance from each other is 478,530,000 miles and if we assume that the velocity of light is 190,000 miles per second, light would require $\frac{478530000}{190000} = 2518.5$

seconds = 41m. 58.5s. for traversing the distance between the two planets. If an eclipse of the satellite takes place, say at 3 o'clock in the morning, while the Earth is at the distance just stated, we should not observe the occultation of the satellite until 3h. 41m. 58.5s., because the last ray emitted by it before disappearance requires just 41m. 58.5s. for reaching the Earth. The next eclipse takes place 42h. 28m. 36s. later, that is, on the following day at 9h. 28m. 36s. in the evening. But during this interval the Earth has moved towards Jupiter through 2,620,800 miles, and the distance between the two planets is now only 475,929,200 miles ; hence the light requires now only $\frac{475929200}{190000} = 41m. 44.7s.$ to reach the Earth, and we

shall observe the beginning of the eclipse at 10h. 10m. 20.7s. ; or, between the first eclipse, which was observed at 3h. 41m. 58.5s. in the morning, and the next, which was observed at 10h. 10m. 20.7s. in the evening of the following day, there is an interval of only 42h. 28m. 22.2s., while the actual interval between one occultation of the satellite and the succeeding one is 42h. 28m. 36s. Thus for an observer on the Earth, when this planet approaches Jupiter, the eclipses succeed each other in shorter intervals than those which actually elapse. On the other hand, when Jupiter is at c_1 , and the Earth at c , the latter planet recedes from the former, and in this relative position light requires between each succeeding

occultation a continually increasing time for travelling through the increasing distance between the two planets ; hence the eclipses appear to be retarded, and the interval between one and the next is now 42h. 28m. 49·8s.

The retardation or acceleration of the eclipses of Jupiter's satellite may be calculated, as has been shown, from the known velocity of light. It is clear that the preceding mode of reasoning may be reversed, and that from the difference between the observed and the calculated times of the eclipses the velocity of light may be deduced. This was indeed the first method by which it was found that light requires time in order to pass from one point of space to another, and it was thus calculated that it passes in one second through 190,000 miles ; subsequent observations have, however, shown that the distances between the planets were formerly taken to be somewhat greater than they really are, and the velocity of light is now known to be about 186,000 miles per second.

Air and other gaseous substances, except those which are coloured, permit light to pass through them without hindrance, unless they are rendered cloudy by suspended dust or fog. If air is very pure, as is the case on high mountains, light passes through distances of many miles without being sensibly diminished. Most liquids also are *transparent*, but not in so perfect a degree as gases ; many liquids, even those which seem quite transparent, appear coloured when viewed in thick strata ; thus a layer of pure water 2 metres thick appears of a bluish tint. Of solid bodies only a comparatively limited number permit light to pass readily—for example,

rock-salt, rock-crystal, the diamond, and several other crystallised minerals, glass, &c. Others are *translucent*—that is, they transmit light, but not without disturbing sensibly the direction in which the light proceeds, and hence objects cannot be distinguished when seen through them; ground glass, oiled paper, woven fabrics, belong to this class of bodies. Most solid bodies, however, unless they are in the form of a very thin layer, do not permit light to pass through them; they are *opaque*.

When light falls in one direction upon an opaque body, a portion of the space immediately behind the body will remain dark. This portion of space is called the *shadow*. The form which the shadow assumes in each case depends on the shape and extent of the luminous body as well as of that which causes the shadow, and it depends also on the distance between the two bodies. In empty space and in air, light is propagated strictly in straight lines, and from this fundamental fact the form of the shadow may be deduced in every case.

Let L in fig. 239 represent the flame of a common paraffin lamp, and let K_1, K_2, K_3 , three discs of cardboard attached to a knitting needle, be the bodies which cause the shadows S_1, S_2, S_3 , respectively, which are received on a white rectangular screen.

The ray of light which is emitted by a , the highest point of the flame, and passes close to the highest point of the body K_2 , reaches the screen at e , while the ray which issues from the lowest point of the flame, and passes close to the lowest point of K_2 , reaches the screen at f , and obviously no ray of light can reach the space intermediate between e and f . This space is the 'true

shadow' or '*umbra*.' If, as is here the case, the body which causes the shadow is of the same magnitude as

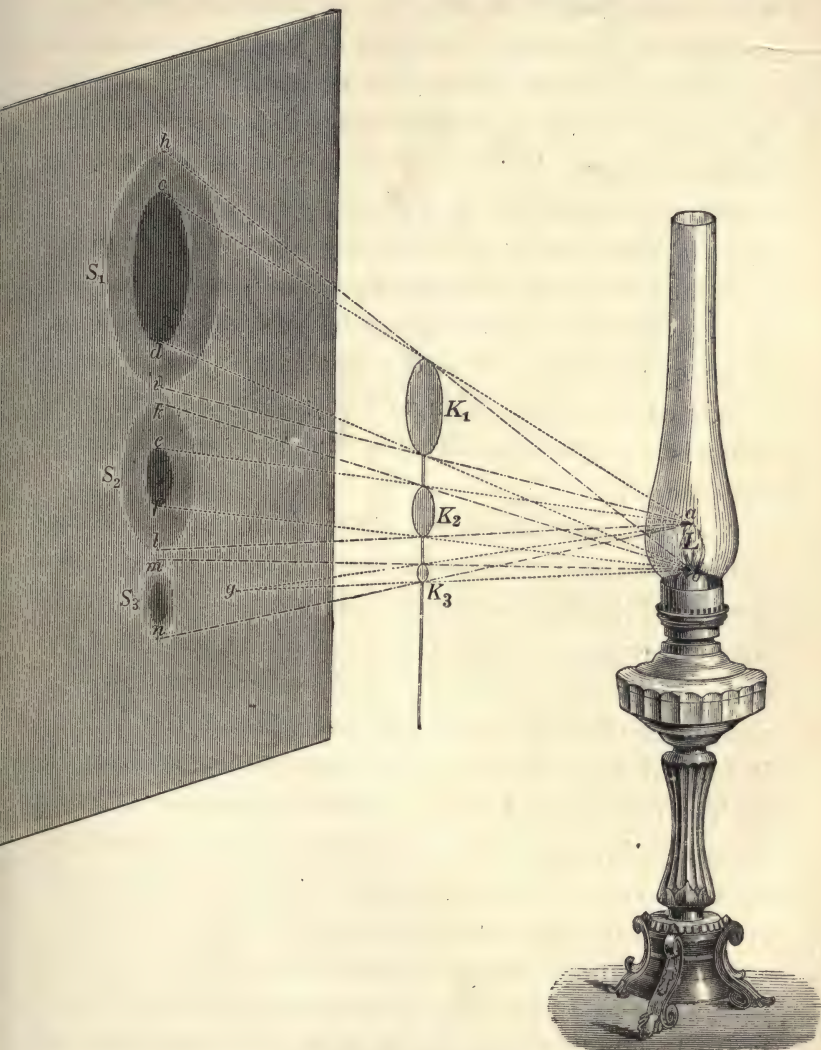


FIG. 239 ($\frac{1}{4}$ real size).

the source of light, then the true shadow will have the same dimensions in length and width as those of

the opaque body which causes the shadow, whatever the distance between the opaque body and the screen on which the shadow is received. If the opaque body is larger than the source of light, as is the case with K_1 , the umbra (defined by the lines $a c$ and $b d$) will increase in length and width as the distance between screen and body increases. Finally, if the opaque body is smaller than the source of light, as K_3 , the umbra (between $a g$ and $b g$) decreases as the distance of the screen from the body increases, and no umbra is produced when the screen is removed beyond a certain point, here indicated by g .

An eye which is situated within the true shadow of a body cannot see anything of the source of light; the latter is completely covered by the body which causes the shadow.

A certain portion of space round the umbra is partially obscured; this space receives light only from a portion of the luminous body, and is called the 'partial shadow' or *penumbra*. The limits of the penumbra are found by drawing straight lines from the highest point of the source of light past the lowest point of the opaque body, and from the lowest point of the former past the highest point of the latter ($a i$, $b h$, $a l$, $b k$, $a n$, $b m$); or, generally, lines must be drawn from one side of the circumference of the luminous body to the opposite side of the circumference of the opaque body.

The penumbra is not equally dark throughout, like the umbra; where it adjoins the umbra it is so dark that it can hardly be distinguished from the latter, but it becomes gradually less and less dark towards the external boundary and there it passes imperceptibly into the space upon which the light falls freely. In all cases, as

the distance of the opaque body from the source of light increases, the penumbra becomes wider and wider, and, properly speaking, reaches to an infinite distance ; but as the distance increases, it becomes fainter and fainter and finally almost imperceptible.

An eye situated within the penumbra sees a portion of the source of light, and the more the nearer the eye is to the outer margin of the penumbra. Again, if the eye is in a straight line behind the opaque body, but the latter is smaller than the source of light, then it will hide the central portion of the luminous body, while the edge remains visible.

Any flame may be used for these experiments, but the flame of a common paraffine lamp is particularly suitable, for it burns brightly, and is rather wide without being too high. Circular pieces of cardboard, fixed one over the other upon a knitting-needle, are used for producing the shadows. Of the three discs the upper one should be twice as large as the flame, the middle one of the same size as the flame, and the lower one should be just half as large. The needle is clamped in the retort-stand, and the shadows may be thrown upon the wall, the lamp and stand being placed upon a table close to the wall. A proper moveable screen is, however, much better, and is useful for other optical experiments. It is best to have a frame made by a joiner for the purpose, and to stretch paper over it; the frame should be from 4 to 6 decimetres high and broad, made of wooden laths, 2^{cm} wide and 6 or 8^{mm} thick. Common writing-paper may be used; but if it is intended to show the experiments to a large audience, tissue-paper is better, for it is translucent, and the shadows may be seen on either side of the screen. The writing-paper must be laid upon the table and damped, before stretching it upon the frame, with a clean moist sponge or cloth; the frame is then covered on one side with a layer of glue, pressed upon the moist paper, raised with the latter and turned over; the paper should then be well pressed everywhere upon the frame. When dry the paper will be tight and smooth. Tissue-paper cannot be moistened without tearing it; it hardly bears the moisture of the glue or gum, and it should

be fixed by means of a very thin layer of Canada balsam spread upon the frame, proceeding otherwise as in the case of the writing-paper; but the dry tissue-paper should be carefully tightened upon the frame with the fingers, so as to remove creases as much as possible. The Canada balsam must be allowed to dry a little upon the frame, if it is very thin; otherwise the paper will not adhere to the frame when the latter is raised. The fingers may be cleaned from the Canada balsam with oil of turpentine.

The screen may be clamped in the retort-stand whenever required; or, more conveniently, it may have a handle attached to the frame, 10 or 20^{cm} long and 1.5 or 2^{cm} thick. The handle is either clamped in the retort-stand, or a little paper is wrapped round it and it is stuck into a candlestick like a candle.

The fact that the eye placed within the umbra sees nothing of the source of light, while an eye within the penumbra sees a portion of the luminous body, may be demonstrated by making holes in the screen with a stout pin in the proper places, and applying the eye to the holes, viewing the discs and flame from behind the screen.

When the screen is close to the opaque body the umbra is nearly of the same size as the latter; the penumbra forms in this case only a very narrow border round the umbra, and the shadow represents faithfully the outlines of the figure of the opaque body. The smaller the source of light, the narrower becomes the penumbral border, and consequently the more sharply defined is the figure formed by the shadow.

The earth and the moon are both much smaller than the sun, from which both receive light. They are therefore both accompanied by an umbra, which extends into space and ends at a definite distance from either body. The umbra of the moon extends to a distance of about 240,000 miles, which is nearly equal to the distance of the moon from the earth. If the moon, during its revolution round the earth, comes into a position which is in the straight line between the

earth and the sun, the shadow of the moon reaches the earth, and we have an *eclipse of the sun*. The distance of the moon from the earth is, however, variable. If the moon, when an eclipse takes place, is at its least distance from the earth, then the extreme part of the umbra reaches the earth and obscures a small portion of the latter ; at those parts of the earth which are situated within the umbra the eclipse is *total*, while at those situated within the penumbra the eclipse is *partial*.

When the moon is at its greatest distance the umbra does not reach the earth at all ; the moon then appears to be smaller than the sun, and those who are exactly behind the point of the umbra observe an *annular* eclipse. In most eclipses the moon does not pass exactly through the straight line between sun and earth ; in that case only a portion of the penumbra reaches the earth, and hence most eclipses of the sun are only partial.

When the moon passes through the umbra of the earth an *eclipse of the moon* take place, which is either total or partial, according as the moon enters completely or only partly into the umbra. The portions of the umbra of the moon which can reach the earth can only be of small extent, and only a small portion of the surface of the earth can be at any time eclipsed by it. But it is different in the case of the earth's umbra, which at the distance of the moon from the earth has still a diameter which is three times greater than the diameter of the moon, and can thus obscure the latter very easily. When the moon enters the penumbra of

the earth a diminution of its light takes place, but this is usually not even noticed.

The farther away a surface is from the source of light the less is the intensity of the light which the surface receives. This is easily seen from fig. 240, in which three surfaces, *A*, *B*, *C*, are placed at the distances

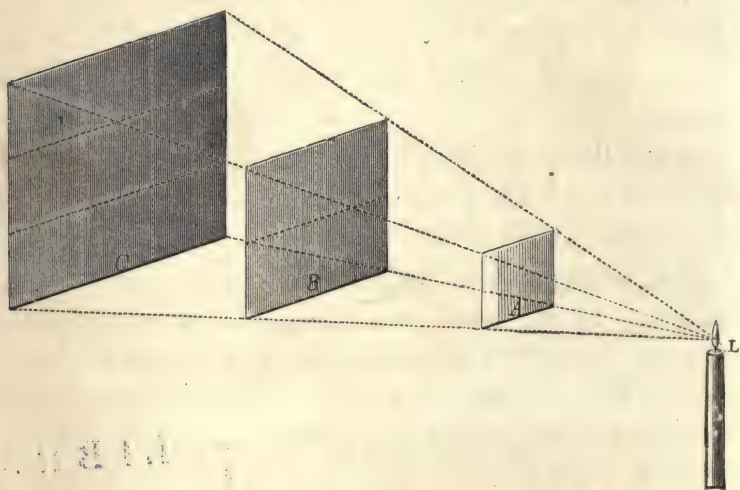


FIG. 240 (*an. proj.*).

LA , LB , LC from the flame L , the distance LB being twice LA , and LC being three times as great as LA . The same amount of light that is cast upon A would be cast upon B , a surface four times as great; therefore the intensity of light there is one-fourth of what it is at A . Again, the same amount of light that is cast upon A would be cast upon C , a surface nine times as great; hence the intensity there would be one-ninth of what it is at A . The distances being therefore expressed by the numbers 1, 2, 3, &c., the intensities will be expressed by the numbers 1, $\frac{1}{4}$, $\frac{1}{9}$, &c., or, generally, the

intensity of light diminishes as the square of the distance from the source of light increases ; in other words : *the intensity of light is inversely proportional to the square of the distance.*

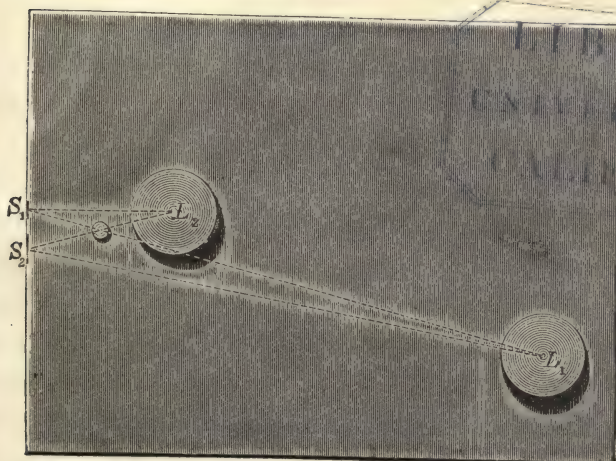
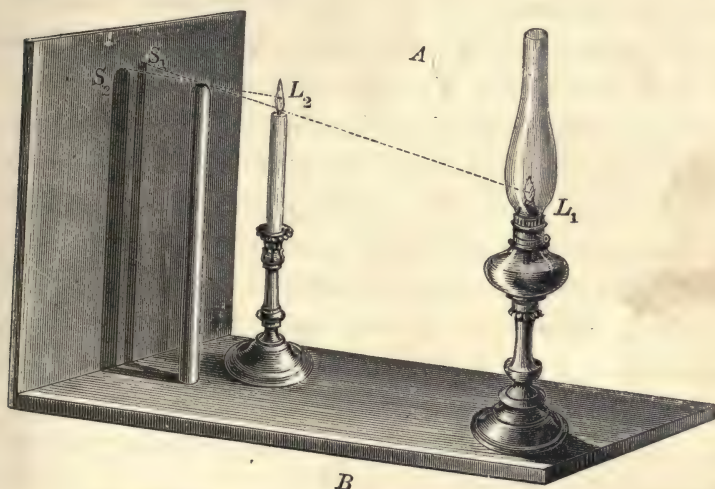


FIG. 241 ($\frac{1}{8}$ real size ; A and B an. proj.).

A luminous body at a greater distance from a surface cannot illuminate the latter with the same intensity as

another luminous body which is at a less distance from the surface, unless it gives out much more light, or, as it is termed, has a greater illuminating power than the nearer source of light. Since the intensity of the light at twice the distance is one-fourth, and at three times the distance one-ninth, it follows that if two sources of light, of which one is placed at a certain distance from a surface, while the other is placed at a distance twice or three times as great, produce equal degrees of illumination, the illuminating power of the more distant body must be four or nine times as great compared with the illuminating power of the source of light which is nearer to the surface. Hence, *when two sources of light produce equal intensities of light upon two surfaces at unequal distances, their illuminating powers are in the ratio of the square of their distances from the illuminated surfaces.*

This law is applied in 'photometry,' that is, the measurement of the relative intensity of different sources of light. There are various kinds of 'photometers' used for this purpose.

Rumford's Photometer (fig. 241, A), consists of a screen, in front of which is fixed an opaque rod; the lights to be compared—for instance, a lamp and a candle— L_1 and L_2 , are placed at a certain distance, in such a manner that each projects on the screen a shadow of the rod, S_1 and S_2 , close to one another. The distances of the sources of light are adjusted so that both shadows appear equally dark. The illuminated portion of the screen receives light from both sources; the shadow S_1 produced by the lamp L_1 receives light from the candle L_2 only, while S_2 , the shadow produced by

the candle L_2 , receives light from L_1 only ; hence if both shadows are of equal intensity, the illumination due to each light must be the same, and it is only necessary to measure the distance from the screen to each source of light, and to square these distances, in order to find the ratio of the illuminating powers. If the distance of the lamp L_1 from the shadow S_2 , which receives light from it, is 56^{cm} , and the distance of the candle L_2 from the other shadow S_1 is 16^{cm} , then the ratio of their illuminating powers is $56 \times 56 : 16 \times 16$, or $3136 : 256$. The intensity of the light of the lamp is to that of the candle in the ratio of 3136 to 256, or in other words it is $\frac{3136}{256} = 12.25$ times as great.

The screen may be opaque or semi-transparent. The vertical rod of the retort-stand may serve as an opaque rod. Care should be taken that the light from both sources falls very nearly perpendicular upon the screen. Fig. 241, *B*, shows a plan of the arrangement ; in both figures the lines L_1S_1 and L_2S_2 serve merely to indicate the direction of the shadows ; the distances to be measured are, L_1S_2 and L_2S_1 . As long as lamp and candle remain in their positions their respective distances from the shadows cannot be conveniently measured ; it is therefore best to draw a line with chalk round the feet of the candlestick and lamp, then to remove both, and to measure the distances from the screen to the centres of the two circles. In making an actual experiment the distances are taken considerably greater than in the above numerical example.

An insurmountable difficulty in these experiments arises from the fact, that two sources of light never emit light which is of equal whiteness. The light of a candle is always somewhat more reddish than that of a paraffine lamp ; hence the shadow projected by the lamp S_1 —that is, the portion illuminated solely by the candle—has a more reddish tinge than the other shadow, and in consequence of this difference in the colour of both shadows it is impossible to decide whether both are equally illuminated.

When a piece of paper, in the middle of which a faint

grease-spot is made, is held before a window, or, in the evening, before a lamp, so that the paper is illuminated from behind, the spot appears light on a dark ground, for the greased portion transmits more light than the surrounding part of the paper. If, on the contrary, the paper be illuminated by light placed in front of it, the spot will appear darker than the surrounding part of the paper: the greased portion allows more light to pass than the ungreased portion, and therefore the latter reflects more light, in other words it appears brighter. If the paper be held nearly with its edge towards the window or the lamp, and slightly turned to and fro, a position will be found in which the greased part and the rest will appear almost alike: when this is the case, the intensity of the illumination on both sides is the same.

Bunsen's Photometer (fig. 242), depends upon this principle. A paper screen, in which a circular grease spot is made, is placed in the straight line between the lights to be compared, and moved in this line to and fro until the grease-spot disappears. It is now only necessary, as in Rumford's photometer, to measure the distance of each light from the illuminated screen, and the ratio of the squares of these distances will give the ratio of the illuminating powers of the lights used.

Bunsen's photometer is very well adapted for proving the law that the relative intensities of two sources of light are in the ratio of the squares of their distances from the two surfaces which they respectively illuminate, when the illumination of both surfaces is the same. For the purpose of this proof, a single candle is used as a source of light on one side of the screen, and a combi-

nation of four candles on the other side. The illuminating power of the combination being four times that of the single candle, it will be found that the grease-spot disappears when the four candles are twice as far

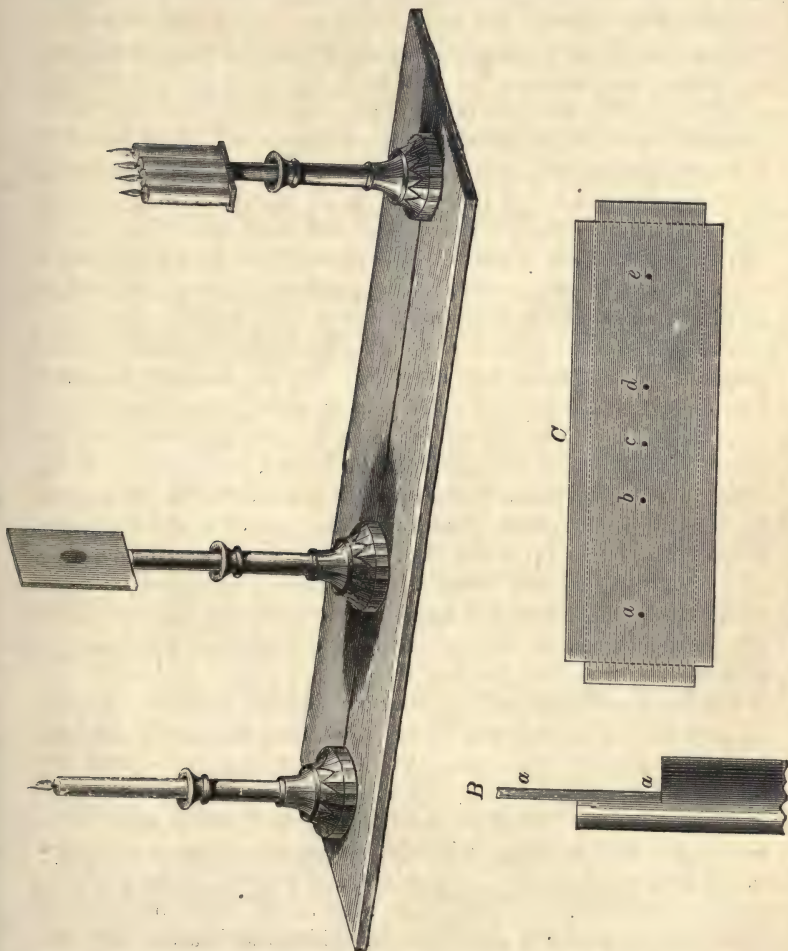


FIG. 242 (*A*, *an. prcj.*, $\frac{1}{2}$ real size; *B*, *C*, $\frac{1}{2}$ real size).

from the screen as the single candle. In fig. 242 the distances are 25^{cm} and 50^{cm} ; the squares of these distances are 625 and 2500; but $2500 : 625 :: 4 : 1$, or

$$\frac{2500}{625} = 4.$$

The grease-spot is made with stearine: tallow or oil produces a yellowish and fatty spot, which soon becomes dirty by adhering particles of dust. The spot must be very faint if it is to be rendered invisible when the illumination is equal. Let one or two drops of stearine from a burning candle fall upon paper, and after a little time remove cautiously with a knife the solid stearine which has not penetrated the paper. The spot is now too strong, but it may be rendered fainter by placing the paper between a few layers of blotting-paper, and putting a hot smoothing iron on it for a short time on the top. The stearine is thus again liquefied, and a portion of it is absorbed by the blotting-paper. By repeated trials it will soon be found how long the hot iron should remain upon the paper, so as to produce a spot of the proper kind—not too strong nor too faint; for in the former case it will not disappear when equally illuminated, and in the latter case it will not be distinct when the illumination is unequal. The paper when thus prepared is glued upon a small frame of wood, with a short handle, made by a joiner, or if needful a cardboard frame, fixed upon a wooden handle prepared with a knife, may be used. The handle should be of a thickness which allows of its being conveniently fixed in a candle-stick, and that side of the frame upon which the paper is stretched should be exactly over the middle of the handle, as shown at *a a*, fig. 242, *B*. A straight line is drawn with chalk on a long table; the lights to be compared are placed upon the ends of it, and the screen moved to and fro upon the line. The distances are in this case also most conveniently measured by drawing circles with chalk round the three supports of lights and screen, removing the latter after the experiment, and measuring the distances of the centres of the circles from one another.

For the experiment with the four candles (fig. 242, *A*), a suitable support for the candles may be prepared from a piece of sheet-tin, 4^{cm} wide and 13^{cm} long. Cut off at each corner a square piece, 5^{mm} each way, punch five holes, as shown in fig. 242, *C*, and bend each side 5^{mm} from the edge, so as to produce a shallow tray. Four tacks, 1·5 or 2^{cm} long, with flat heads, are thrust from underneath through the holes *a*, *b*, *d*, and *e*, and soldered to the tray; this is done by moistening each tack with a drop of soldering fluid, placing close to each a small piece of solder, and heating the whole over a gas or spirit flame, until the solder flows into the space between the head of the tack and the tray. Another tack is driven through the hole *c* in a contrary direction; it serves for fastening the tray to a wooden handle, while the four spikes formed by the other tacks serve for fixing the candles upon them. The turned-up edge of the tray prevents the stearine from running down at the side.

The five flames should be carefully trimmed, so as to be as nearly as possible of equal size; their magnitudes may be measured with a piece of wire bent like a hair pin and used like a pair of compasses. Careful attention to this point is needful to make the experiment give approximately correct results.

39. *Reflection of Light. Mirrors.*—The surfaces of solid and liquid bodies ‘reflect’ rays of light which fall upon them, and it is only by the light thus reflected that bodies which are not self-luminous are rendered visible. Reflection of light varies in degree, according to the condition and nature of the reflecting surfaces. Let an open book be held with its back turned towards, and somewhat below, the flame of a lamp which illuminates a room in the evening; the open page will be in the shadow, and the print can scarcely be read. If now a flat bright body, such as a piece of paper, be held a little farther away from the lamp, and higher than the book, the print will appear sufficiently bright, at any rate upon the upper portion of the page, to be read easily. Even holding up the hand in the place of the paper will sensibly increase the light which falls upon the page. If instead of the paper a small square piece of looking-glass is held in the same position, a portion of the page will be rendered much brighter than in the case of the paper; moreover, the portion illuminated will now have a sharply-defined boundary which separates it from the rest, which remains dark. Thus, a well-polished surface like that of a mirror reflects light in a definite direction, while rough and dull surfaces reflect light in all directions.

The curved side of the shallow semi-circular vessel represented in fig. 243 is divided into eighteen equal parts,

that is, from 10 to 10 degrees. The division in the middle is marked 0, the two on each side next to it are marked 10, the next 20, and so on as far as 90. Beginning with 0° , there are apertures from 10° to 10° .

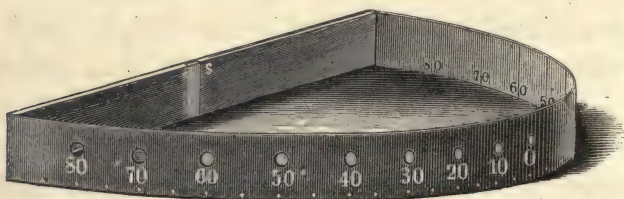


FIG. 243 (*an. proj.* $\frac{1}{6}$ real size).

Opposite to the aperture at 0, in the flat side of the vessel, is a small mirror, *s*, which is so adjusted that on looking through the aperture opposite to it the reflected image of the aperture is seen exactly in the middle of the mirror, which is only the case when the straight line drawn from the aperture to the mirror is perpendicular to the latter.

If the eye is applied to the aperture at the division 10° , the division 10° on the other side of 0° will be seen in the mirror; if the mirror is observed through the aperture at 20° , the opposite division, 20° , will appear reflected, and so on. At whatever angle the light is incident upon one side, it is reflected at the same angle on the other side.

This experiment on the law of reflection is still more striking if performed in a dark room. If instead of the eye the flame of a candle is placed pretty close to one of the apertures, light passes through it, and the portion which is incident upon the mirror is reflected in such a manner as to illuminate the corresponding line

of division on the other side, and also the number placed by the side of it.

When a ray of light meets a surface at a point the line drawn perpendicular to the surface at that point is called 'the perpendicular at the point of incidence;' the line from 0° to the centre of the mirror is such a perpendicular for all rays which are incident upon the centre of our mirror. Our experiments prove that light is reflected so that the ray of light makes, after reflection, the same angle with the perpendicular as it made before reflection. This angle, which light incident upon a surface makes with the perpendicular, is called the 'angle of incidence,' while the angle made with the perpendicular after reflection is termed the 'angle of reflection.' Hence, the first law of reflection may be enunciated thus: *the angle of reflection is equal to the angle of incidence.* The second law of reflection is usually stated thus: *the incident and the reflected ray, and the perpendicular to the surface at the point of incidence, lie in the same plane.*

The apparatus in fig. 243 is made of a board, cut semi-circular with a saw; to the straight side a wooden rim is fixed 4 or 5^{cm} high; the semicircular rim, having the same height, is made of cardboard. The diameter of the semicircle should be from 30 to 60^{cm}. The strip of cardboard is first cut of larger size than required, placed tightly along the edge of the semi-circular board and fixed temporarily by means of a few tacks, driven to about half their length through the cardboard into the semi-circular edge of the board, and also at both ends of the semicircle into the side of the straight wooden rim. At each end of the semicircle a pencil line is now drawn, so as to mark off precisely the length of cardboard required, and this is to be divided into eighteen equal parts. The strip is then taken off the board, and cut to the required length, leaving at each end, beyond the pencil line, a piece as wide as the thickness of the wooden rim, so that the end of the cardboard may be fixed upon the latter. The strip is again straightened, divided, and

the divisions distinctly marked with numbers (see p. 75, line 9); apertures 1^{cm} wide being made in the proper places, and the strip is finally fixed permanently with glue and tacks.

The small piece of looking-glass, 2^{cm} wide and 4^{cm} high, should be cut by a glazier. It is fixed with a cement, made by melting together in a metal spoon equal parts of resin and yellow bees' wax, and stirring the mixture. When gently warmed, this mixture becomes so soft that it may be moulded with the fingers. It is applied only to the edges of the mirror, not to the silvered back, which would be injured by it. While fixing the mirror the eye should be applied to the aperture at 0°, so as to give the correct position to the mirror. It is still better to have a groove cut in the wooden rim into which the mirror closely fits.

Let SS in fig. 244 represent the surface of a mirror upon which rays of light fall from the point a , and

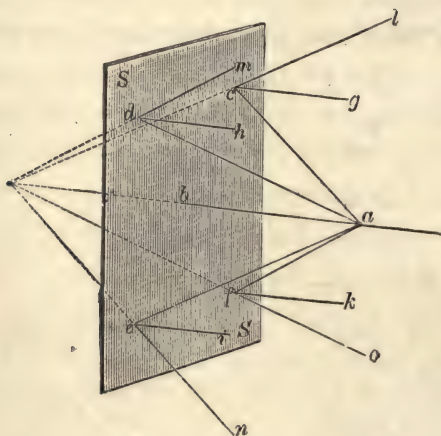


FIG. 244 (*an. proj.*).

let the lines ab , ai , ad , ae , af represent some of the rays. If the ray ab is supposed to be perpendicular to the surface, it will coincide with the perpendicular at the point of incidence of the ray ab , and the lines cg , dh , ei , fk will be the perpendiculars at the points of incidence of the four other rays. The ray ab is reflected back in its own direction, while the reflection of

the other rays takes place in such a manner as to make the following angles equal: $acg = gcl$, $adh = hdm$, $aei = ien$, and $afk = kfo$. Thus the rays will have the same divergence after reflection as they had before it, and will proceed as though they came from a luminous point a' , situated upon the prolongation of the perpendicular ab , as far behind the surface of the mirror as the point a is in front of it. Upon an eye placed before the mirror the reflected rays will thus make the same impression as if they actually proceeded from a' , the eye will in fact *see* the point a' . This point a' is called *an optical image of the point a*.

Every point in a body which is placed before a mirror gives rise in the same way to an optical image of itself,

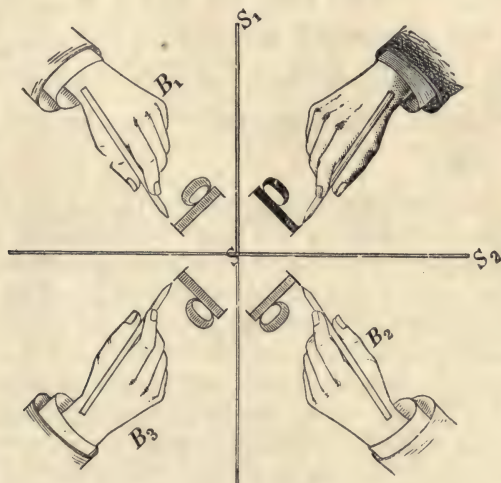


FIG. 245 ($\frac{1}{8}$ real size).

and the images of all the separate points produce together the image of the whole body, equal to it in magnitude and corresponding to it in form. Nevertheless, a change in position is observable in the images of bodies

which are differently shaped on both sides, as, for example, the hand, many letters, &c.; thus the image of the right hand is like the left hand, the image of the letter **p** is like the letter **q**. This is called *lateral inversion*, and in all these cases the reflection does nothing more than shift the point of divergence of the rays, from right to left, and from left to right. If the image is again reflected from a second mirror, lateral inversion takes place a second time, and the second image is therefore in every respect like the original. If two plane mirrors, SS_1 and SS_2 , in fig. 245, are placed vertical and at right angles, their edges touching one another, an object placed within the angle will in the first instance produce one image in each mirror, B_1 , and B_2 ; but each mirror with its image is again reflected by the other mirror; these reflected images must obviously mutually coincide, and hence a third image, B_3 , is produced, which agrees in every respect with the original object.

Two rectangular pieces of good silvered plate-glass, not less than 15^{cm} long and 10^{cm} wide, or still larger if possible, are placed upon pieces of cardboard of the same size, so as to protect the silvering, and glass and cardboard are fixed together all round the edges with strips of black paper, or fine ribbon, glued to the sides, so that only a very small edging is left round the reflecting surface. The back of the cardboard may be covered with paper to give it a better appearance. The two mirrors are joined together along the smaller side by hinges of black ribbon, as long as the mirrors are wide, and glued across the back of the mirrors, while these are placed with exactness over one another, their reflecting sides being in close contact. The mirrors will open and close afterwards like a book, and may be inclined to one another at any angle and placed in a vertical position upon any horizontal surface.

Place them in this manner nearly at right angles, and look at the edge where they join. The image B_3 will at first appear inexact: either a piece in the middle will be wanting, or it will appear double.

If the position of the mirrors is not very incorrect, and you look at the image of your face, the nose and mouth of the image will appear either somewhat too narrow or too broad, but if the position is very incorrect, only adjoining edges of the face are seen, the middle portion being not visible at all, or a double face appears; the correct inclination of the mirrors may easily be found after a few alterations by way of trial. The difference between the second image (that is, the image of the first image) and the first image itself may be recognised by placing a finger to one eye—for example, upon the right eye: the second image places the finger also upon the right eye, while the ordinary image places it upon the left eye.

If the angle between the mirrors is smaller than a right angle, the number of images formed is greater. Thus at an inclination of 60° the two first images are each reflected twice again, but as two of these reflections coincide and give but one image, we have altogether five images; if the angle is 45° , we have three reflections of each primary image, and hence seven images, which, with the object itself, form the eight angular points of an octagon, while, in the case of the five images produced when the angle between the mirrors is 60° , the figure formed is a hexagon.

The *kaleidoscope* is a tube which contains two small mirrors, placed lengthwise in the interior of the tube, and inclined to one another at an angle of either 60° or 45° . One end of the tube is closed by two parallel discs of ground glass placed almost close to one another; the space between the discs contains small pieces of coloured glass, bits of twisted glass of various shapes, &c., which appear as a symmetrical figure with six or eight rays when looked at through an aperture in the opposite end of the tube. There is just room enough for the small bodies to tumble about, and hence an endless variety of symmetrical combinations present themselves to view as the tube is turned.

When the kaleidoscope is held in the usual way—that is, in a nearly horizontal position directed towards a window or a lamp—the small bodies collect near the lower edge of the disc; to give a greater variety to the figures, the tube should be held vertically downwards, light being reflected into the tube by means of a mirror which receives it from a window, the mirror being held in the proper position by the retort-stand.

If the two moveable mirrors are opened only about 4 or 5^{cm}, and a short piece of a small wax taper be placed in the opening, a whole wreath of flames will be formed by repeated reflection; the circle of flames can, however, only be completely seen by applying the eye very closely to the opening of the angle formed by the two mirrors.

A mirror does not reflect the whole of the light which falls upon it; hence the reflected image is never so bright as the object which is reflected, and the images become fainter and fainter after repeated reflection. This is also seen in the kaleidoscope, for the different parts of the figure are not equally bright: the part opposite to the one which is seen by direct light is always the least bright. For investigating repeated reflection a bright object, such as a very luminous flame, must be selected, as otherwise the images will not be visible after the reflection has been repeated a number of times.

The experiment with the candle should only last just long enough for observing the result; otherwise the mirrors might crack by the heat of the candle, or the amalgam at the back might be injured.

Two parallel mirrors would produce an infinite number of reflected images of an object placed between them, if there were not so much loss of light as to render the images at last invisible. Nevertheless, if a candle be placed between two mirrors, a long series of images will be observed, which are placed along a straight line if the two mirrors are exactly parallel, but appear along a curve if the mirrors are even slightly inclined to one another.

Two pieces of looking-glass, about as large as those used for the inclined mirrors, are fixed vertically by two retort-stands, 15 or 20^{cm} distant from, and parallel to, one another. A burning candle is placed between them, and the eye applied close to the edge of one of the mirrors, so as to see the greatest possible number of reflected images.

Common glass mirrors give rise to a double reflection; for images are not only produced by the silvered surface at the back, but also by the plane polished front surface of the glass. The image produced by the metallic surface possesses, however, a much greater intensity of light than the reflection from the surface of glass, and is usually alone observable; but on holding a burning candle, *k* in fig. 246, pretty close before a

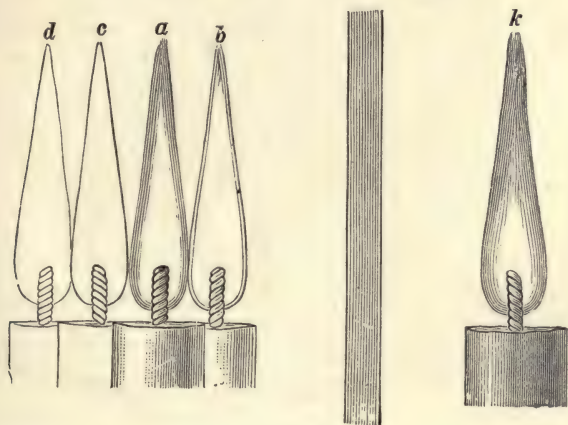


FIG. 246 (*real size*).

common mirror, a distinct image, *a*, is seen to be reflected by the silvered surface, and a more feeble one, *b*, is reflected from the glass surface of the mirror; but besides these there are several other reflected images seen, whose intensities gradually decrease. These images arise from the repeated reflections which take place between the two surfaces.

A piece of unsilvered plate-glass produces not only a reflected image of an object placed in front of it, but also allows light to pass through it from objects behind it. It may thus be arranged that two objects appear

in the same place. An eye at *a*, fig. 247, sees the image of a candle flame, *f*, reflected by the plate of

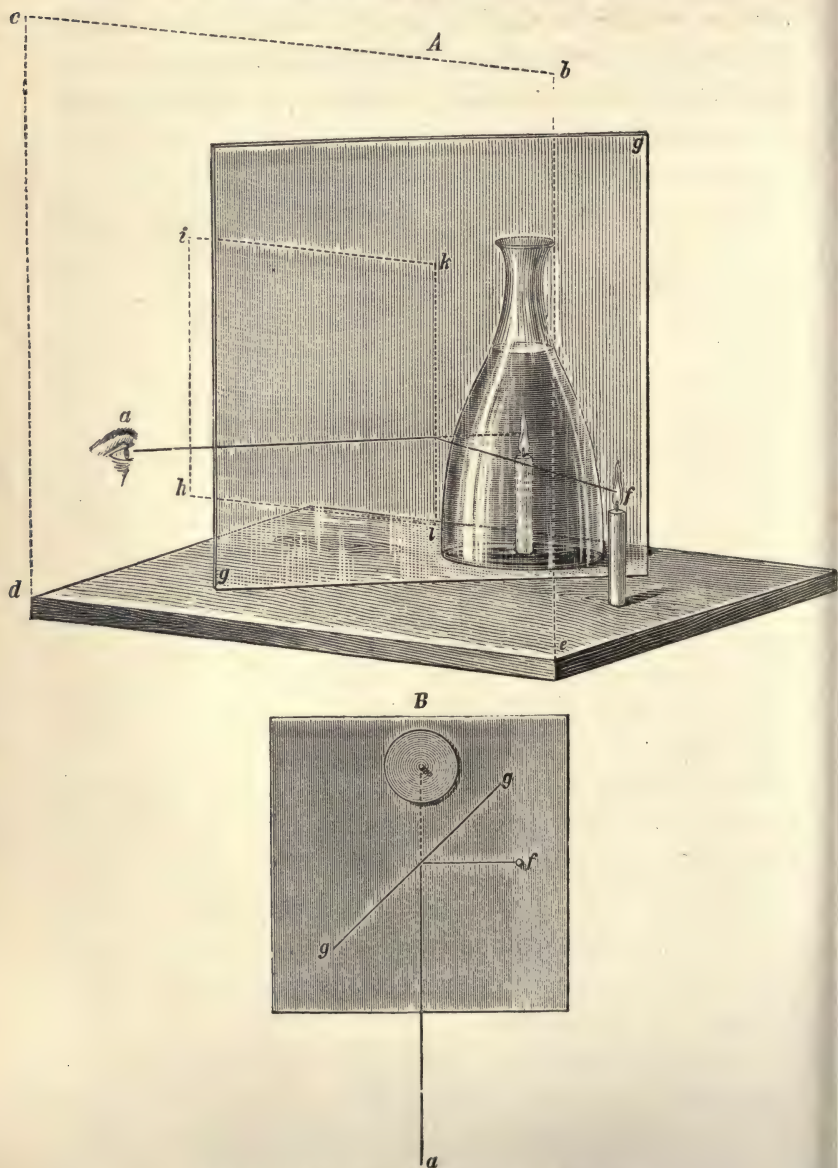


FIG. 247 (*A*, an. proj., $\frac{1}{8}$ real size; *B*, $\frac{1}{16}$ real size).

glass *gg*, in the interior of a decanter. Fig. 247 *A* shows the phenomenon itself, while *B* gives a plan of the arrangement.

It is in this manner that ghosts and other spectral phenomena are produced on the stage. A large sheet of plate-glass is placed in front of the stage so that its edges are hidden by a framework of scenery; and the actors on the stage are thus seen, but not the glass itself. In front of the glass, below the proscenium, and thus hidden from the audience, is a space where the objects or persons to be reflected are arranged; a strong light is thrown upon them when they are to make their appearance, and, the glass plate being inclined to the audience, the reflected images appear behind the glass as if they were upon the stage opposite to the spectator.

For the experiment shown in fig. 247 a pane of window-glass should be fixed in a suitable manner in the retort-stand, and a piece of cardboard, having a rectangular aperture, is arranged so as to hide the edges of the glass and also the flame itself. The illusion will be specially perfect if the experiment is made in the evening, and care is taken that no other objects, upon which the light of the candle may fall, are reflected by the glass. The dotted line *b c d e* indicates the edge of the cardboard, the line *h i k l* that of the aperture.

Reflecting surfaces which are not plane give rise in general to distorted images, as may be easily seen on observing the reflection of the face in a bottle of dark glass, by a bright button, a soap-bubble, or any similar surface. Images which correctly conform to an object placed at a definite distance from the reflecting surface can only be produced by such curved surfaces as form a portion of a sphere, and have only a

slight curvature, whether the reflection takes place from the internal or the external face—that is, whether the reflecting surface be concave or convex.

Spherical mirrors are thus either concave or convex mirrors. The centre of the hollow sphere of which the mirror forms part, c in fig. 248, is called the

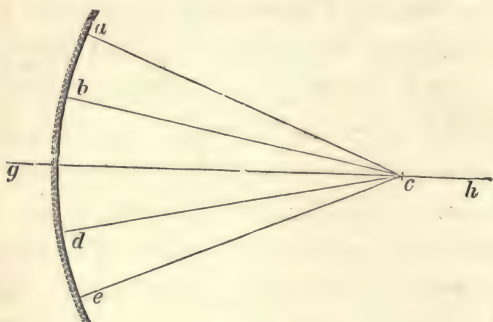


FIG. 248.

centre of curvature. Lines drawn from the centre of curvature to any point of the mirror, as ac , bc , dc , ec , are *radii of curvature*; further, the infinite straight line gh , which is conceived to pass through the middle of the mirror, g , and the centre of curvature, c , is the *principal axis* of the mirror.

The mode of reflection of light from curved mirrors is deduced from the laws of reflection from plane mirrors, by considering the surface of the former as made up of infinitely small plane surfaces, which are called its *elements*. A radius of curvature drawn from the centre to any point of the mirror is perpendicular to the surface at that point; hence rays of light which emanate from a luminous point situated in the centre of curvature are reflected back again in their own direction to the centre.

If a luminous point be not in the centre, but somewhat above it, although at the same distance from the mirror as the centre, as *A* in fig. 249, then the incident rays do not coincide with the perpendiculars at the points of incidence: they are somewhat above these perpendiculars, and consequently the reflected rays will

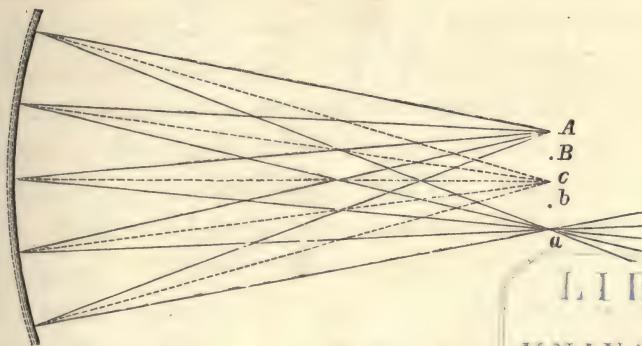


FIG. 249.

be as much below, and converge to a point *a*, which is the image of *A*. In the figure the full lines represent the incident and reflected rays of light, the dotted lines are the perpendiculars at the points of incidence.

If the light emitted by *A* is of sufficient intensity, the image formed by the convergence of the reflected rays may be received at *a* upon a small screen, and this image can be clearly seen in various directions; if the screen is translucent, it will be seen on both sides. If no screen is placed at *a* for the reception of the image, the latter can only be seen by looking in the direction of the mirror itself; the eye will then receive the rays which proceed beyond *a*, after having crossed at that point, and the same impression will be produced as if the rays actually proceeded from *a*.

LIBRARY
UNIVERSITY
CALIFORNIA

Whenever, as in the preceding case, reflected rays converge, and coincide at a point in front of the mirror, on the same side as the object, the image formed is called a *real image*, for it can be received on a screen. But if the image has no real existence, and the luminous rays do not actually meet after reflection, but their prolongations coincide in some point, as is the case with images produced by plane mirrors, the appearance is called a *virtual image*. The distinction may be expressed by saying that real images are formed by the reflected rays themselves, and virtual images are formed by the prolongations of the incident rays.

The point B situated between A and the centre of curvature c gives an image at b , between the image a and the centre. A body placed above the centre of curvature will present a series of points to the mirror, and a corresponding series of images of points will give by their combination an image of the body, but inverted; that is, the whole image of the body will appear upside down, but of the same size as the body itself. This may be clearly seen from the relative positions of A , B , and a , b . If the body were placed to the right of c , a corresponding inverted image would be formed to the left of c .

Concave mirrors made of glass with silvering at the back produce multiple images, which with mirrors of this kind have a still more disturbing effect than in the case of plane mirrors. Proper images are only obtained if the *front* of the curved mirror is formed by a polished metallic surface. Carefully ground metallic mirrors of this kind, such as used for telescopes, are expensive, because they are difficult to construct; but concave mirrors, sufficiently accurate for studying the images produced, may be prepared by the student, using for the purpose an alloy of lead and tin. The mirrors thus produced have a somewhat wavy surface, and give slightly blurred

images not to be compared with the sharply-defined images of good concave reflectors; the lustre of their surface is also very soon tarnished. This latter defect is, however, easily remedied by making a new mirror, while the mirrors thus produced are well adapted for projecting a distinct image of a candle flame upon a screen. The alloy is made of 29 parts of tin and 19 of lead; it melts easily, and if a clean surface of glass is pressed upon the molten liquid, just when it becomes nearly solid again, a very bright impression of the surface will be obtained. For making a concave mirror a curved piece of glass, a so-called convex lens, is used; in fact any burning-glass will do for the purpose, but it is best to use a kind of lens about 6^{cm} in diameter, mentioned in the next paragraph. This lens is only slightly convex—a very convex one produces obviously very concave impressions, but they are nearly useless on account of the distortion of the images produced. This distortion is always great, and the image blurred, if the width of the mirror is more than $\frac{1}{12}$ th of the radius of curvature, and the concavity exceeds the $\frac{1}{10}$ th part of the width; in fact, what has been stated above of concave mirrors holds good strictly only for mirrors of which the concavity is within the limits just mentioned. Mirrors which have such a small curvature (and this is the only kind used for astronomical purposes) require a rather large space for exhibiting the various kinds of images which they produce. It is therefore more convenient to use for experimental demonstrations mirrors of somewhat greater curvature. In our figures for illustrating the formation of images the curvature is always represented as greater than it actually is, or otherwise the figures could not have been apportioned to the size of the page. The actual curvature of our lens is such that the centre is raised by about $\frac{1}{40}$ th of the width of the lens. The concave mirror will accordingly have a corresponding depression of its centre.

Prepare two square pieces of stout millboard, each side about 10^{cm} long, and out of the middle of one of them cut a circle having its diameter a few millimetres shorter than that of the lens; glue both pieces flat upon each other, and they will form a shallow circular mould for receiving the molten metal. The glue must be thoroughly dry before the mould is used, and even then bubbles of vapour will be driven out of the millboard by the hot metal. It is therefore necessary to pour liquid metal once or twice into the mould, and allow it to get cool in it, so as to have it thoroughly dried.

A large cork glued to the lens serves as a handle. It should be slightly hollowed out on the side where it is attached, so as to require as little glue as possible—a thick layer is difficult to dry, and softens again when the glass is warm.

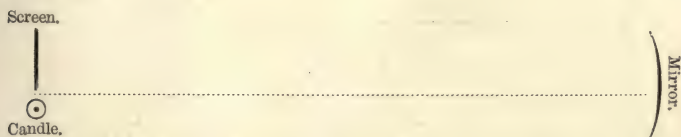
Melt in a ladle 114^{gr} (6×19) of lead and 174^{gr} (6×29) of tin, and stir the molten liquid with a splinter of wood. It should not be poured out too hot. To avoid this, let it cool in the ladle after melting, and then heat it again; pour out when a small portion is still unmelted. The dull grey film which during the melting is formed on the surface of the alloy remains behind in the spoon, if the metal is allowed to run into the mould from the edge of the circular vessel. The latter will, in that case, be filled with pure bright metal. The metal should stand about 2^{mm} above the edge. As soon as a few small dull spots appear on the bright surface, which indicate that the mass is beginning to solidify, take a piece of stiff paper, draw its edge over the surface so as to remove all particles which have become solid, and to make the surface bright again; and now immediately press the lens upon it, holding it somewhat inclined, and placing it thus upon the metal. If laid on horizontally, too many air-bubbles will remain between glass and metal. It should also be pressed down very quickly and be immediately lifted up again, or it will crack in consequence of the heating. Immediately after lifting up the glass a cracking sound is usually heard; it is due to the partial separation of the metal from the glass. When quite cold the metal will part from the glass of itself, or a slight help with the finger will make it separate. There are always layers of vapour and condensed air upon the glass, both of which cause numerous bubbles to appear on the surface of the metal. The first and second casts are, from this cause, mostly quite useless. These casts are therefore melted again, and the third cast is generally satisfactory, even if a few vesicles should still make their appearance. The whole is now turned out, the glass below and the metal on the top, and upon the latter a piece of sealing-wax, 3 or 4^{cm} long, is pressed, which melts at the end, and adheres after cooling, so as to serve as a handle for clamping the mirror into the fork of the retort-stand.

Such thin mirrors are easily bent out of shape, especially when some force is applied in separating the glass from the metal. The glass should, therefore, not be pressed too deeply into the molten mass, while on the other hand care must be taken lest the metal reaches or overflows the edge of the glass. Before proceeding to the actual casting some preparatory practice with a piece of common glass is advisable, in order to obtain the requisite facility in pressing down and raising the glass without cracking it.

The metallic surface has, immediately after solidification, the exact figure and outline of the glass, but soon afterwards, sometimes even before the glass is completely removed, the surface shows fine

ripples, which are the more imperceptible the nearer the metal was to becoming solid again at the moment when the glass was pressed upon it, and the thinner the metallic layer happened to be. The surface has a bright polished appearance when new, which may be preserved very long if care is taken to protect the surface against the touch of the fingers and dust. It is immediately tarnished when touched and wiped, and should therefore be kept with the polished side turned downwards.

A screen of cardboard, covered with white paper, is clamped vertically in a retort-stand, and placed in a dark room as close to a candle as is possible without burning the cardboard. The concave mirror is fixed by its handle in a second retort-stand at a distance of a few decimetres from the candle, at the same height as the latter, so that the light reflected by it impinges upon that part of the cardboard which is in close vicinity to the candle. Object and image should be as near as possible to the axis of the mirror. The position of the latter should therefore be such that a line drawn from its centre to the edge of the screen nearest to the candle may be a perpendicular both to the mirror and to the screen. This is indicated in the following diagram.



The mirror is now moved in the same position towards or from the screen. If the image of the flame becomes larger during this motion, move the mirror in the opposite direction, and a position will soon be found in which a well-defined inverted image of the flame and the more brightly illuminated upper portion of the candle makes its appearance on the screen.

The distance at which the image has its best definition is equal to the radius of curvature of the mirror; our lens would produce a mirror of $0^m.3$ radius. The image of the flame appears at its best definition somewhat smaller than the flame itself, because the flame has no sharp boundary line, and the intensity of the light of the image is always less than that of the luminous object. This disadvantage may be avoided in the following manner. Cut a small triangular aperture in the screen, 6 or 8^{mm} broad and 20 or 25^{mm} high, the vertex of the triangle being above. Place the candle behind the aperture, so that it may throw its light through the opening upon the mirror, which will thus reflect an image not

of the candle, but of the aperture, and will project the image close to the aperture itself. Try first, by holding a piece of paper at the spot where the mirror is to be placed, whether a bright light is received through the aperture, and afterwards place the mirror so that it may be just in the middle of the bright triangular beam of light seen on the paper.

Rays which are parallel to the axis of a concave mirror, and are reflected by it, meet after reflection in a point which, as the point f in fig. 250, is exactly as

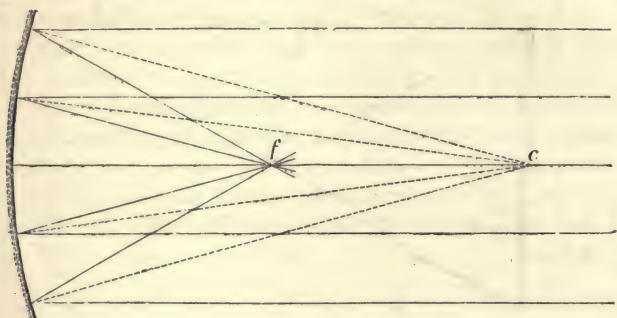


FIG. 250.

far from the middle of the surface of the mirror as from its centre of curvature. This point is called the *principal focus* of the mirror, and the distance of the focus from the mirror, which is half of the whole length of the radius of curvature, is called the *focal length* of the mirror.

Since rays parallel to the axis are reflected to the focus, it is obvious that rays which proceed from the focus are reflected in directions parallel to the axis.

Rays which proceed from a point near the axis either meet after reflection in a point near the axis, and produce at that point a real image of the luminous point, as in fig. 249, or the rays diverge after reflection,

and appear to proceed from a point behind the mirror and close to the axis, thus producing a virtual image.

The mode of reflection of those rays which are either parallel to the axis or proceed from the focus enables us to construct the path of any two rays which proceed from any luminous point whatever, if placed before a mirror, and to find the point where they meet after reflection. This point is nothing else than the position of the reflected image of the luminous point; for from the point from which *two* rays of light issue all other rays given out by that point must clearly proceed, and the point where *two* rays meet after reflection must be the point of intersection of all other reflected rays.

We have already seen that (*the image of a luminous object, whose distance from the mirror is equal to the radius of curvature of the latter, is inverted, equal in magnitude to the object, and at the same distance from the mirror as the object.*)

Let now, as in fig. 251, an object AB be farther

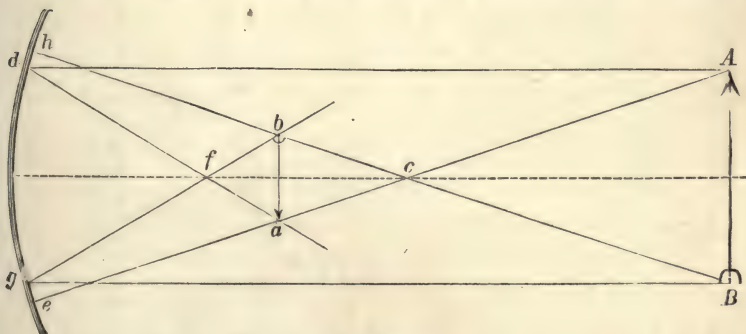


FIG. 251.

from the mirror than twice the focal length; that is, let its distance be greater than the length of the radius of curvature. The ray $A d$, parallel to the axis, is re-

flected towards the focus f ; the ray $A c e$, which passes through c , the centre of curvature, is reflected upon itself, that is in the direction $e c$; both directions intersect in a ; hence at a is the position of the image of A . The rays $B g$ and $B c h$ which proceed from B are reflected in directions $g f$ and $h c$; these intersect in b ; hence b is the image of B . All points between A and B produce images between a and b ; hence $a b$ is the image of the object $A B$. (*The image of an object whose distance from the mirror is greater than twice the focal length is formed between the focus and the centre of curvature, is inverted, smaller than the object, and real.*)

From the law of the equality of the angles of incidence and reflection it follows immediately that rays proceeding from the points a and b would form images respectively at A and B , and that $A B$ would then become the image of an object $a b$. (*The image of an*

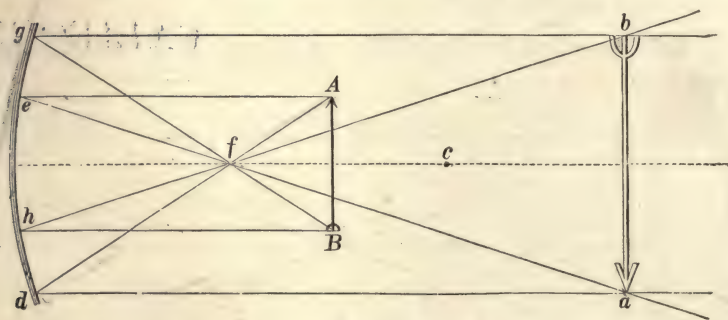


FIG. 252.

object between the focus and the centre of curvature is formed at a distance from the mirror greater than twice the focal length, is inverted, larger than the object, and real.)

The same result may be found in a different manner. Let $A B$, fig. 252, be again the object, c and f the

centre of curvature and focus. A ray Afd passing through the focus is reflected parallel to the axis, in the direction da ; a ray Ae , parallel to the axis, is reflected in a direction efa , which passes through the focus. The point of intersection a is therefore the image of A . Similarly the rays emitted by B intersect at b , as seen by following the directions $Bfgb$ and $Bhfb$; hence b is the image of B .

If an object is in the focus, no image is formed; the reflected rays are parallel to the axis; they do not intersect at, nor do they appear to proceed after reflection from, definite points.

Finally, let an object be between the mirror and the focus, as in fig. 253. The ray Ad from A , parallel to

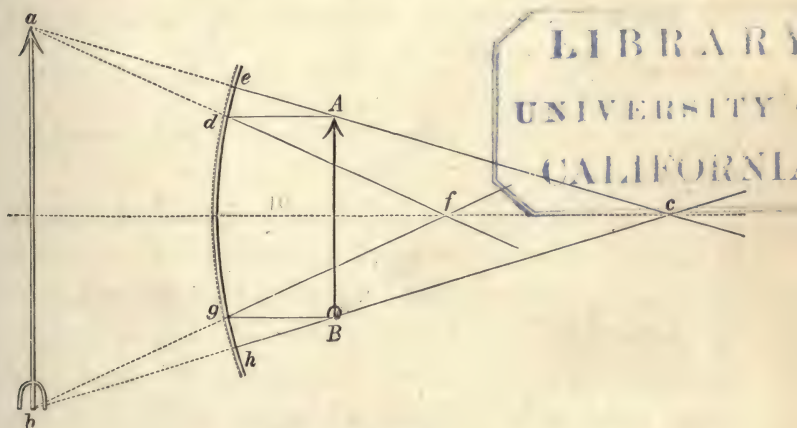


FIG. 253.

the axis, is reflected towards the focus f ; the ray Ae , which is in a line with the centre of curvature, is reflected back upon itself, but the reflected rays df and Ac do not intersect, they diverge and appear to proceed from a , a point behind the mirror; hence a is a virtual image of the point A . The rays Bgf and

B h B c give similarly the point *b* as image of *B*, and hence *a b* is the image of *A B*. (*The image of an object between the mirror and its focus is erect, larger than the object, and virtual.*)

The distance from the mirror of the image may be found by the following rule, if the distance of the object from the mirror and the focal length are known:— Divide the product of the distance of the object into the focal length by the difference of the two quantities; the quotient is the distance of the image. Thus for a mirror of 20^{cm} focal length and a distance of 30^{cm} between object and mirror, the distance of the image is $\frac{30 \times 20}{30 - 20} = 60^{\text{cm}}$ (that is, in front of the mirror); if the object is 10^{cm} from the mirror, we obtain by the same rule $\frac{10 \times 20}{10 - 20} = -20^{\text{cm}}$ (that is, behind the mirror, as indicated by the opposite sign which precedes the result).

The relative magnitude of object and image is always in the ratio of their respective distances from the centre of curvature. In the last example the centre of curvature is 40^{cm}, the object 10^{cm} in front of the mirror; their distance from one another is therefore 30^{cm}. Again, the image which is 20^{cm} behind the mirror is 60^{cm} from the centre of curvature; that is, its distance from it is twice as great as that of the object; hence the image has twice the size of the object. In the previous case the distance of the object from the centre of curvature is $40 - 30 = 10^{\text{cm}}$, that of the image $60 - 40 = 20^{\text{cm}}$; the image is therefore in that case also twice as large as the object.

The real images produced in the cases where the object is at a distance either greater or less than twice the focal length may be represented in a similar manner to that shown in the first case, where the distance was equal to the radius of curvature. The relative positions of screen, candle and mirror for either case will appear from the following diagrams.

IMAGE LARGER THAN OBJECT.

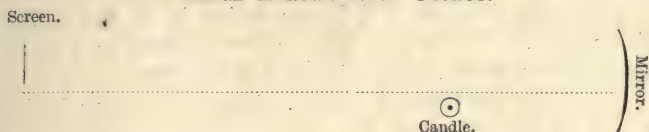
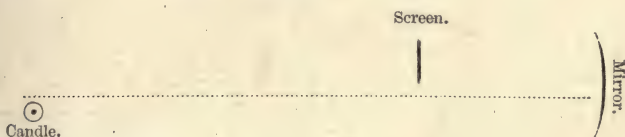


IMAGE SMALLER THAN OBJECT.



The magnified image may be received on the screen of tissue paper described in the preceding article, but the smaller image should be received on a piece of thin writing-paper. Both images will then be visible on either side of the screen. The small image cannot be received on the paper screen with wooden frame if it is desired to see it from both sides, for if it is to be produced near the axis of the mirror it would fall on the opaque frame. The proper distances between mirror, screen and object required for producing well-defined images, can be found after having them approximately arranged as in the above diagrams, by moving only one of the three to and fro until the image obtains the best definition. In the case where the image is smaller it is best to move the screen only; in the case where the image is magnified move the candle.

For a mirror of 15^{cm} focal length (radius = 30^{cm}) a distance of the object of 20^{cm} corresponds to a distance of the image of 60^{cm}; and if the former distance is 25^{cm}, the latter is 37^{cm}.5. In the first case the image is 3 times, and in the second case 1½ times, as large as the object. In all cases the positions of object and image are interchangeable: if the object be placed at the distance given for the image in either of the foregoing examples, the image will be found to be formed at the distance given as that of the object in the same example.

A greatly magnified image may be obtained by throwing the image of a candle upon the wall of the room. A very small image may be produced by placing the mirror as far as possible from the window, and projecting in daylight the image of the window upon a small screen of thick white paper; if the screen is semi-transparent there is too much direct light from the window for a clear definition of the reflected image, whether it be viewed from one side or the other.

The erect, magnified, virtual image which is produced behind the mirror may be observed by holding the mirror like a common looking-glass at a short distance in front of the eyes.

In order to observe the real images without screen, as indicated in fig. 249, mirror and candle are set up in their proper places, and by moving the head to and fro the most suitable position of the eye may be found. The diminished image is more easily found than the magnified one. This mode of viewing the images leads easily to an optical deception, for the observer is apt to judge the images to be situated behind the mirror, although they are in reality in front of it, as may be proved by receiving them upon a screen. This deception is more easily produced by small concave mirrors than by large ones; but even with small mirrors like those used in our experiments the probability of illusions may be avoided, and the judgment assisted by receiving the image first upon a translucent screen, looking at the side of the screen which is turned away from the mirror, and finally removing the screen.

The images produced by *convex mirrors* present less variety. The image is in all cases behind the mirror, for convex reflecting surfaces do not bring rays of light to convergence, but cause the incident rays to diverge after reflection, and thus to appear as if proceeding from points situated on the other side of the mirror. Fig. 254 exhibits the mode in which a number of rays proceeding from the point *A*, are reflected. The perpendiculars at the points of incidence, that is the radii of curvature drawn from the centre to these points and produced, are indicated by lines formed of alternate dots and dashes, while the dotted lines represent the reflected rays

produced backwards. The reflected rays take directions as if they proceeded from a ; hence a is the image of A .

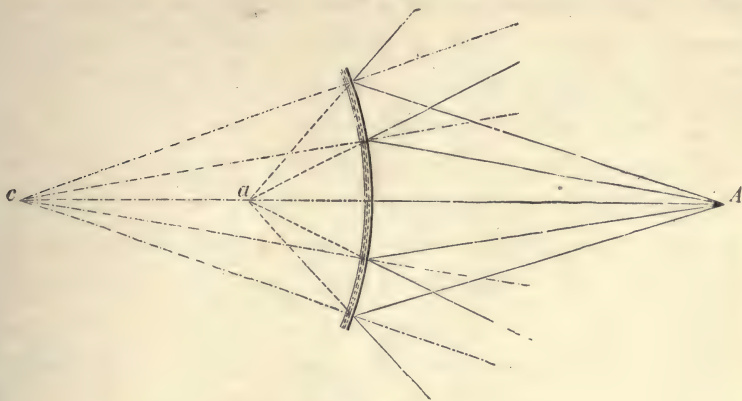


FIG. 254.

A ray of light incident in a direction perpendicular to the surface of a convex mirror, that is in the direc-

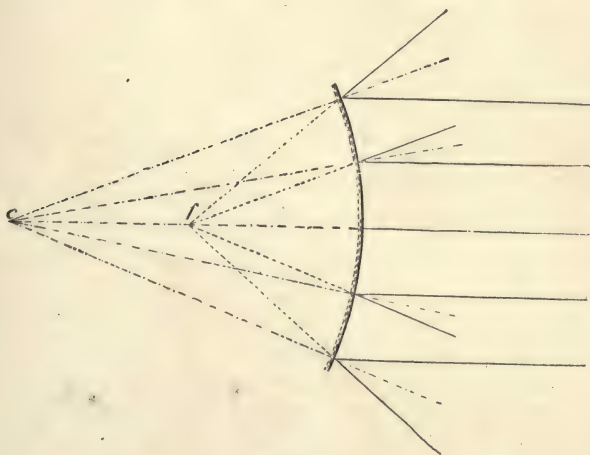


FIG. 255.

tion of a radius of curvature, is reflected upon itself; rays parallel to the axis are reflected as if proceeding from a point f , midway between the surface of the

mirror and its centre of curvature. The point f is called the *principal focus* of the convex mirror, being in this case, however, not a real focus as in the case of concave mirrors, but a principal *virtual* focus; its distance from the mirror is the *focal length* of the latter.

As in the case of concave mirrors, the place, position and magnitude of images produced by convex mirrors may be found by drawing from each of the extreme points of an object, straight lines representing rays of light proceeding from these points, and tracing the path after reflection of two such rays, one being drawn to the centre of curvature, the other parallel to the axis. The ray $A d$, fig. 256, drawn from A to the centre of

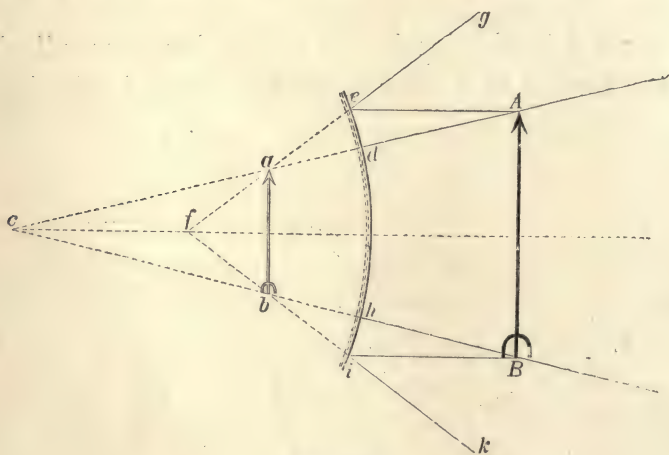


FIG. 256.

curvature c , is reflected upon itself, that is, in the direction $d A$; the ray $A e$, which proceeds from A parallel to the axis, is reflected so as apparently to proceed from f , that is, in the direction $e g$. Both rays, like all the others which emanate from A , take after reflection a direction as if proceeding from the point a ;

therefore a is the image of A . Similarly b is the point of intersection of the rays hB and ik produced backwards; therefore b is the image of B . *The image of an object placed in front of a spherical convex mirror is formed behind the mirror, is erect, smaller than the object, and virtual.*

The distance of the image formed by a convex mirror is found by multiplying the focal length into the distance of the object and dividing by the *sum* of these two quantities. The ratio of the magnitudes of object and image is for convex as well as for concave mirrors equal to the ratio of their respective distances from the centre of curvature. Let an object, 10^{cm} high, be 15^{cm} distant from a convex mirror of 40^{cm} radius and therefore of 20^{cm} focal length.

The distance of the image is then $\frac{15 \times 20}{15 + 20} = 8^{\text{cm}}.57$;

since the object is in front of the mirror, and the image behind it, their distances from the centre of curvature are respectively $40 + 15 = 55^{\text{cm}}$ and $40 - 8.57 = 31^{\text{cm}}.43$, and the magnitude of the image follows therefore from the proportion $55^{\text{cm}} : 31^{\text{cm}}.43 :: 10^{\text{cm}} : x$

$$= \frac{31.43 \times 10}{55} = 5^{\text{cm}}.71.$$

In the case of convex mirrors it is more easy to find common substitutes than is the case for concave mirrors, and as their images present very little variety, the student need not go to the trouble of producing a regular convex mirror. A common hollow watch-glass supplies a pretty good convex reflector if the hollow surface is blackened with lamp-black. This may be done by means of the flame of a piece of cotton wool, about the size of a pea, fixed to a wire, dipped into oil of turpentine, and lighted. Other flames are not so suitable; they do not deposit so much soot, and heat the watch-glass so much that it often cracks before it is blackened. The bulb of a thermometer filled with mercury, or a glass flask of globular shape (such as often used for chemical experiments) filled with ink, or even a bright metal button of convex shape, may serve for our purpose.

Objects which are not much smaller than the convex mirror used, and still more objects which are larger than it is, should not be brought too near to the reflecting surface, or the images are much distorted. The images of the more distant objects are smaller than those of the nearer. If a body has comparatively large dimensions, some portions of it will be sensibly nearer to the mirror than others, and will hence appear larger than the images of those portions of the same body which are farther from the mirror: this is the cause of the distortion. If the face be brought near to a convex mirror which is rather small, the projecting parts of the face—for example, the nose—will in the image appear larger in proportion than other parts of the face, and the whole will therefore resemble the distorted figure of a human face in a caricature.

40. *Refraction of Light. Prisms. Lenses.*—When light falls upon the surface of a body, a certain quantity, which varies according to the nature of the surface, is reflected; the quantity of reflected light is the greater, the lighter and more polished the surface, and the less, the darker and rougher it is. But even the brightest and best polished metallic mirrors do not reflect the whole of the light which falls on them; a portion of the incident light penetrates in all cases into the interior of the body. If the body is opaque, the light is completely absorbed very near the surface, so that it penetrates only to a very small depth; if the body is semi-transparent, the light is absorbed only gradually, it penetrates deeper, and may even partly pass through the substance; finally, if the body is transparent, the light is only slightly diminished, but it undergoes mostly a considerable change of its original direction; only those rays of light which are incident in directions perpendicular to the surface of a transparent body are permitted to proceed in their original directions.

A rectangular water-tight vessel, such as a tin

biscuit-box, is placed upon the table at such a distance from a lamp or candle that the bottom of the vessel may be just in the shadow of one of the sides, as shown in fig. 257 *A*. The front of the vessel is left out in the figure in order to exhibit the interior, which in reality could only be seen by looking into the vessel from above. If the vessel is now filled with water, the bottom of the vessel, as shown in fig. 257 *B*, is no longer entirely in the shadow; the rays of light

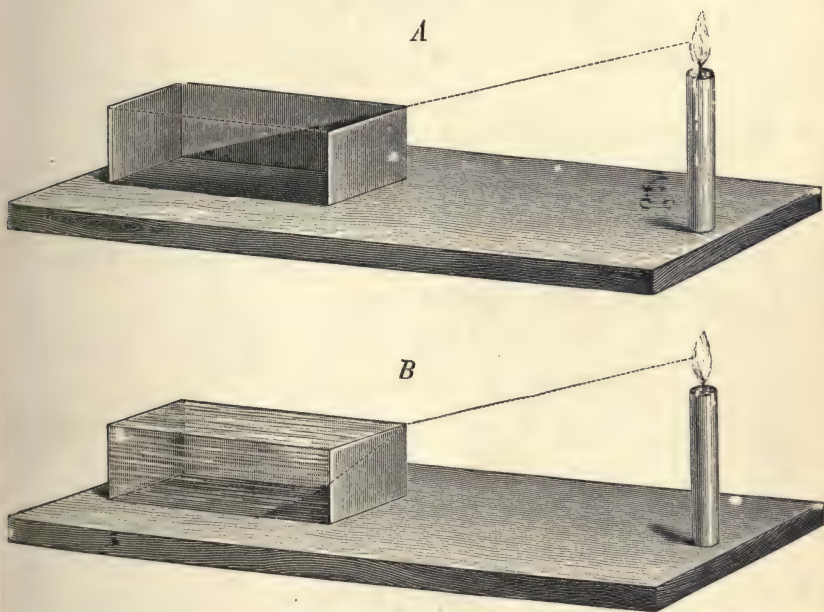


FIG. 257 (*an. proj.*, $\frac{1}{4}$ real size).

which strike on the surface of the water proceed in the liquid in a more slanting direction than that in which they were propagated in the air. This change in the direction of rays of light which pass from one transparent substance (air) into another (water) is called *refraction* of light; the surface where the refraction

tion takes place is the 'refracting surface,' and each of the two substances is termed in reference to this phenomenon 'a refracting medium.'

A round basin may be used instead of a square vessel for showing the refraction of light which passes from air into water. The boundary of the shadow is, however, in that case not a straight line, but a curve, and the equality of the effect of refraction upon the various rays which reach the edge of the vessel cannot be so well observed.

If a small heavy body, for example a coin, be placed in an empty opaque bowl and the observer retires to such a distance that the coin is just hidden from him by the edge of the bowl, the coin comes into view again when the vessel is filled with water, while the eye of the observer retains its position unaltered; in fact, the whole bottom of the vessel will seem to be lifted up, and the vessel will appear shallower than it really is. The reason of this is that light which passes from water into air is refracted in a direction which is the reverse of that in which light is refracted when passing from air into water. The ray of light *a b*, fig. 258, which proceeds

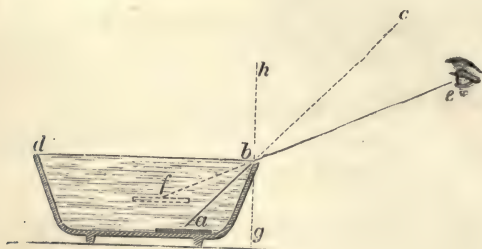


FIG. 258 ($\frac{1}{8}$ real size).

from the body, would take the direction *b c* if the vessel were empty; but on leaving the surface *b d* of the water, it takes in consequence of refraction the direc-

tion $b e$, and the eye at e receives the impression of a ray of light proceeding from f . The angle which the ray incident on the refracting surface makes with the perpendicular at the point of incidence, that is, angle $a b g$ in fig. 258, is, as in reflection, called the *angle of incidence*; the angle made by the refracted ray with the same perpendicular, as $e b h$, in fig. 258, is called the *angle of refraction*. If rays of light pass from air into water, as in the first experiment, the angle of incidence is greater than the angle of refraction; if the light

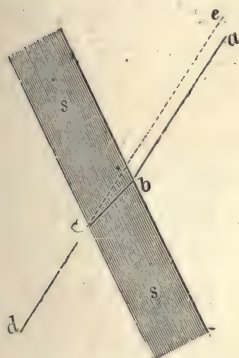


FIG. 259 (4 times real size).



FIG. 260.

passes from water into air, the angle of incidence is less than the angle of refraction. In general, whatever its direction, the ray makes in water a smaller angle with the perpendicular to the surface than it does in air.

No refraction seems to take place when light passes through a common window-pane, provided that both surfaces are quite parallel. Let $s s$ in fig. 259 be a section of a pane, and $a b$ the incident ray. At b refraction takes place, the direction of the ray is now $b c$; at c refraction takes place again, and the direction of the ray is now $c d$, that is, parallel to its original direc-

tion but somewhat displaced; an eye at d sees the object from which the ray ab proceeded as if the object were at e . This lateral displacement is so slight that it is only rarely perceived, viz. when the glass is of unusual thickness. But if the glass has a suitable form, a ray of light is found to be more bent from its original path when passing from air into glass, than when it passes from air into water; glass is hence said to have greater 'refractive power' than water. If one of two rays is incident upon glass and the other upon water, and the angle of incidence is the same for both rays, the angle of refraction will be less in glass than it is in water.

If a ray of light passes from glass into water, as in Fig. 260, or from water into glass, the angle which the ray makes with the perpendicular to the surface, will always be less in glass than in water; in this as in all other cases the law holds good, that of two different substances that one in which the angle between the ray and the perpendicular at the point of incidence (or emergence) is the smaller has more refracting power than the other. It follows from the preceding experiments that air possesses less refractive power than water.

A body possessing the shape represented in fig. 6 (page 6) is called a 'triangular prism.' Prisms of this form made of transparent substances are very well adapted for studying the effects of refraction. Prisms for optical purposes require, however, only two 'refracting surfaces,' that is, two plane faces which are not parallel. Hence a transparent body of any shape provided it has two surfaces inclined to one another, is an 'optical prism.' The edge at which the two refracting surfaces meet is the 'refracting edge' or simply

the *edge*, and the angle between them is the 'refracting angle.'

In fig. 261 *A*, let abc be the section of a prism, of which a is the edge, ab and ac the refracting surfaces. For a ray of light de the perpendicular at the point of

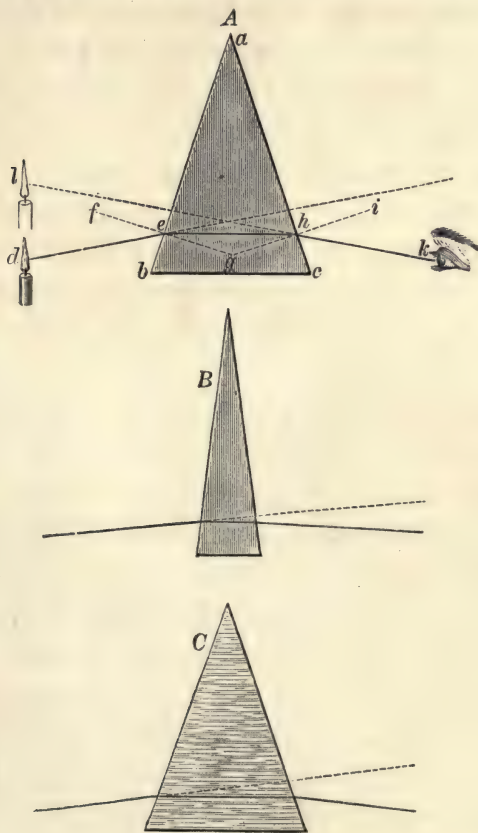


FIG. 261.

incidence is feg . The angle of the ray with the perpendicular is smaller in glass than in air. The ray proceeds therefore within the prism in the direction eh , the angle heg being less than def . At h the ray is refracted a second time; ghi is now the perpendicular at the point of incidence, and ghe the angle of in-

cidence, and the light passing now into a less refracting medium, the angle of emergence must be greater than $g h e$, and $h k$ will be the direction of the ray when it leaves the prism. It follows that if the prism has the position represented in the figure, the ray of light is refracted downwards; in general, a ray of light passing through a prism of higher refractive power than the surrounding medium, is refracted *from* the edge and *towards* the base $b c$ of the prism. An object viewed through a prism appears, on the contrary, nearer to the edge and further from the base, for the ray is bent downwards, and reaching an eye at k has the direction $h k$; the eye receives the impression of luminous rays proceeding along $l h k$, that is, it sees the light of the candle at l .

The *deviation* of a ray of light which passes through a prism is the greater, the greater the refracting angle of a prism, and the greater the refractive power of the substance of which the prism is made. Thus in fig. 261 the prisms A and B are supposed to be both of glass, but the refracting angle of the former is greater than that of the latter, hence the deviation produced by A is greater than that by B ; again, C is a prism of water, having the same refracting angle as A , but the deviation caused by C is less than that caused by A , glass being more refractive than water.

Prisms of liquid substances can of course be formed only by enclosing the liquid substances between inclined surfaces of glass; if the glass plates employed for these purposes have perfectly parallel faces, the rays of light are unaffected by them and suffer solely the deviation due to the liquid.

Sunlight which passes through a window may be

easily deflected by means of a prism; a bright luminous spot may thus be produced upon the floor, where no direct sunlight was received before. The prism may be clamped in a retort-stand placed on the window-sill; if the edge is turned upwards the rays will be refracted and fall upon a spot on the floor which is nearer to the window than the portion illuminated previously by the rays passing directly through the window; if the edge be turned downwards, a beam of light will be sent to a spot farther away, that is, to the opposite wall.

By candle light the deviation of the rays which pass

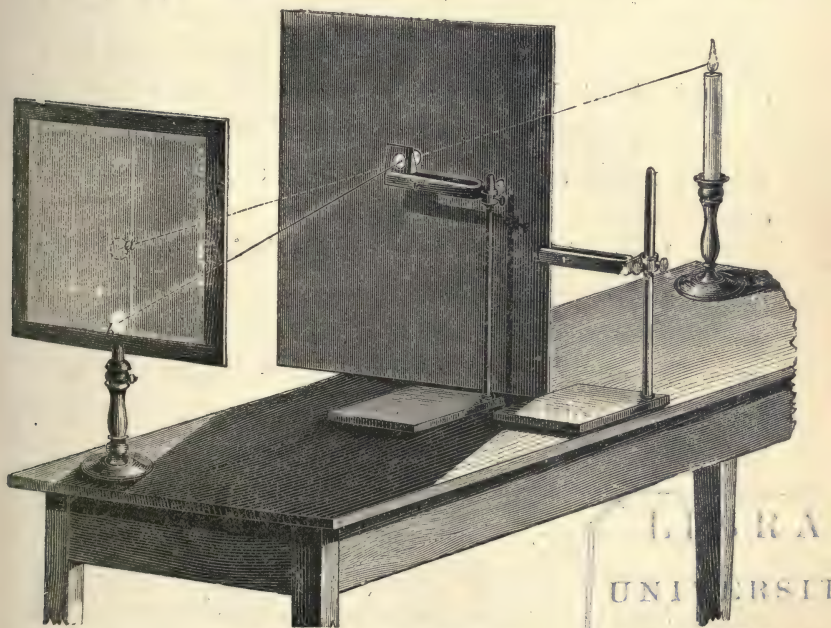


FIG. 262 (*an. proj.*, $\frac{1}{12}$ real size).

through a prism may be demonstrated by the arrangement shown in fig. 262. A sheet of card-board is fixed in a vertical position, about 1^{cm} from the candle, and it has at the same height as the candle flame, a circular

aperture of about 2^{cm} in diameter; about 1^{cm} from the sheet of card-board the screen used for the experiments in Art. 38 is placed. Close behind the aperture is the prism, edge upwards, clamped in the fork of the retort-stand. The beam of light which passes through the aperture previous to the interposition of the prism produces a bright circular spot at *a* upon the screen; but as soon as the prism is placed in the path of the beam, the latter is deflected, and the bright spot appears at *b* instead of at *a*. If the screen is 1^{cm} from the prism, the latter having a refracting angle of 10° and its substance being water, the deviation of the beam measured by a straight line from *a* to *b* will be found to be about 5^{cm}.8; if the angle is 20°, the distance from *a* to *b* is about 11^{cm}.1: and if the refracting substance were glass instead of water, these distances would be half as much again, the refracting angles remaining equal.

The laws which regulate the deviation of light by prisms are somewhat too complex to be discussed in this work. The deviation is not strictly proportional to the refracting angle, and is less nearly so the greater this angle. If one of two prisms has a refracting angle which is double that of the other, the deviation produced by the former will be more than double that of the prism with the smaller angle. The deviation, moreover, does not depend merely upon the substance and refracting angle of a prism, but also on the relative direction which the incident ray has to the first refracting surface; in other words, the deviation changes with the position of the prism relatively to the incident light. If, as assumed in fig. 261, the incident and the emergent ray make equal

angles with the refracting surfaces, the prism produces the 'least deviation;' in all other cases the deviation becomes somewhat greater.

The common kinds of glass prisms, which may be purchased, have mostly a section which is an equilateral triangle. Their re-

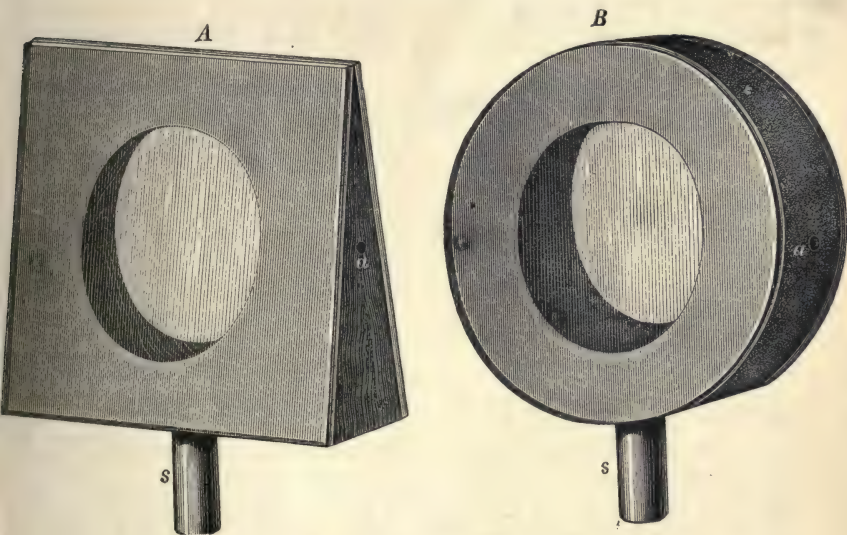


FIG. 263 (*an. proj., real size*).

fracting angle is therefore 60° . They produce generally very irregular refractions, because the glass is not of equal density throughout, and on account of their large refracting angle they give rise to the phenomenon of dispersion of light, which will be discussed in the next article. Such prisms are therefore not very well adapted for our present experiments, for which prisms of water, with moderately large refracting angles, are more suitable. Such prisms may be prepared pretty easily in various ways.

Fig. 263 *A* represents a small wedge-shaped board of hard wood, which should be cut by a joiner; it is about 5cm long and wide; one end is very thin, and the other from 9 to 18mm thick. A circular hole is bored through the middle with a centre-bit, afterwards widened with a keyhole-saw or a sharp knife, and finally rounded off with a half-round file. The space within the hole is to be filled with water, and in order to clamp the water prism conveniently, in the retort-stand, a wooden handle, *s*, is inserted into the side of the

board opposite to the refracting edge. The hole for the handle should be bored with a stout gimlet, but not so deep as to reach the hole for the prism. The handle may be fixed with glue; but if the hole should have been made too deep, sealing wax must be used for fixing it. A hole a , bored into one of the triangular sides by means of a fine gimlet or burnt through with a hot wire, serves for filling the interior afterwards with water; this aperture should not exceed 2^{mm} in width. The refracting surfaces of the prism are formed by thin plates of glass fixed upon the sides of the wedge with

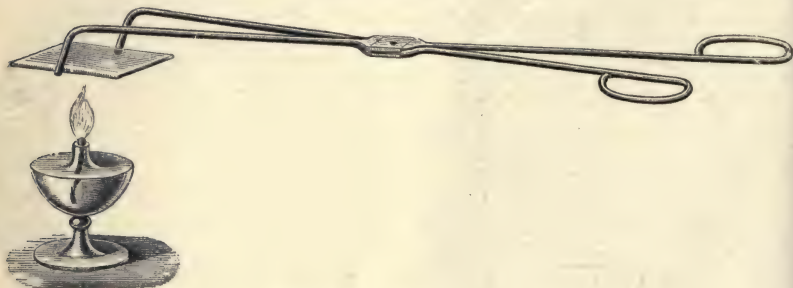


FIG. 264 (*an. proj.*, $\frac{1}{3}$ real size).

sealing wax; the plates may either be cut square by a glazier or prepared with pastille, cutting them first round and then grinding off the edges. First place a thin layer of sealing-wax, which may be softened over the lamp, upon the rim of the wedge; then hold one of the glass plates with a pair of crucible tongs, as in fig. 264, over the spirit-lamp, moving it cautiously to and fro until it is hot enough to melt sealing-wax when touching it, and press it upon the layer of wax on the wedge. When one plate is fixed and has cooled, proceed with the other plate in the same manner. The plate must be heated slowly and not too much, and care should be taken to place it at once in the proper position upon the side of the wedge; otherwise the part through which the light has to pass will become partially smeared over with sealing-wax, which cannot be removed again after the second plate is fixed. All particles of wood which may adhere to the sides after the boring and filing must also be removed previously, as they cannot be easily taken out afterwards through the aperture a . The water is introduced by means of a glass tube about 15^{cm} long and as thick as a pencil; one end of it is drawn out long and thin, and the tube is then filled like a pipette by sucking; the point being inserted into the aperture the water is blown into the interior of the prism and, the operation repeated until it is full. The small aperture must be directed upwards while this is

done, so that the air may escape easily. The aperture need not be closed afterwards, as the water is kept in by the external pressure of the atmosphere; when the prism is to be emptied, the water may be removed by sucking, using the same tube which served for filling the prism. Immediately after using the prism, it is advisable to remove the water as completely as possible, otherwise it penetrates into the wood, which becomes warped in consequence. If it should become necessary to remove the glass plates in order to clean the inner sides, the plates must be loosened by heating them with the greatest caution, as the adhering moisture renders them liable to crack when being heated. The wood should be thoroughly dried before fixing the glass plates again upon it.

For the construction of a second prism a large sound cork, a so-called 'bung-cork,' may be used. Cut from it a round disk, 3 to 5 cm in diameter and 15 to 20 mm thick, which may be employed like the wedge just described. The faces are cut even and filed so that they may slant; a hole is bored through the middle and widened, leaving only a ring of cork as shown in fig. 263 *B*. The thickness of the ring at the top should be 5 mm, and from 15 to 20 mm at the bottom. Opposite to the thinnest portion a hole is bored for the handle *s*, which is fixed with sealing-wax; the hole *a* for filling the prism must in this case be burned with a wire. The glass plates are of course circular in this prism.

Best window-glass, or still better thin plate-glass, should be used. Better kinds of prisms for containing liquids may be made entirely of glass; their construction is described in the next article.

Two prisms having different refracting angles will be required for showing the influence of the magnitude of this angle upon the deviation.

Let, in fig. 265, *b* represent a small prism of glass which refracts a ray of light proceeding from *a* in such a manner that it reaches the point *c*. The prism *d*, having a smaller refracting angle than *b*, produces less deviation, and if the refracting angle be suitably adjusted the ray *a d* may also be refracted towards *c*; similarly, if the prism *e* has a still smaller refracting angle, and the latter is properly chosen, the ray *a e* will meet the other rays also at *c*. These three prisms have their refracting edges directed upwards; three corresponding

prisms, with their refracting edges downwards, viz., the prisms f, g, h , will, if their refracting angles have the required magnitude, refract the rays from a also towards c .



FIG. 265.

Finally, the central ray between the prisms passes from a to c without refraction. It follows that, with a suitable arrangement of prisms, a number of rays which diverge from a may be brought to converge again at a point c .

It will be easily seen that the series of prisms need not be arranged one vertically above the other. Fig. 265 may be supposed to represent a section through a series of prisms arranged in a horizontal line; and in fact, whatever the arrangement of the series, whether horizontal or vertical, or inclined to either of these directions, the effect will be the same: the rays from a which impinge upon the prisms will be refracted towards a point c .

It follows further, since the deviation of a ray does not depend on the distance of the refracting surfaces from one another, but solely upon the angle between them, that a mass of glass of the shape represented in fig. 266 B must have precisely the same effect as the combination of separate prisms represented at A in the same figure. The upper and lower portions of B , viz., a and g , are exactly equal to the prisms a and g in A ; b and f in

B have their refracting surfaces farther apart than *b* and *f* in *A*, but they are in both cases equally inclined to one another, hence they produce the same deviation; *c* and *e* in *B* are much thicker than *c* and *e* in *A*, but here also the refracting angles, and consequently the deviation, is the same. The central portion *d* in *B* has parallel faces, and a ray of light passes through it without suffering deviation; it is the same as if the rays were passing through the empty space *d* in the centre of *A*.

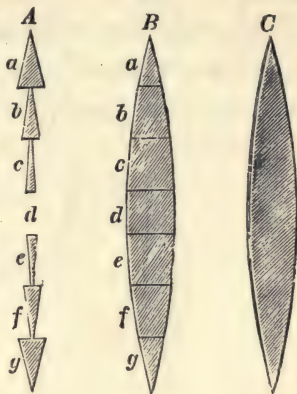


FIG. 266.

A lens of glass, such as *C* in fig. 266, may thus be considered as a combination of an infinite number of prisms the refracting angles of any consecutive pair of which differ infinitely little from each other; and such a lens will serve better for collecting rays which emanate from a luminous point, and bringing them to convergence at some other point, than a series of separate prisms whose refracting angles differ considerably.

Convex lenses of this kind are called ‘converging,’ on account of their action on light. If the lens is bounded on both sides by convex spherical surfaces, as *C* in fig. 266, and *a* in fig. 267, it is ‘double convex;’ if one of its surfaces is convex and the other plane, the lens is called ‘plano-convex,’ as *b* in fig. 267. Another converging lens, *c* in fig. 267, is bounded by one convex

and one concave surface, but the convexity exceeds the concavity; such a lens is called a ‘meniscus,’ and it shares with the two other kinds the property that it is thickest in the middle.

Concave lenses are ‘diverging,’ that is, rays of light diverge after being refracted by them. Fig. 267 *d* is a

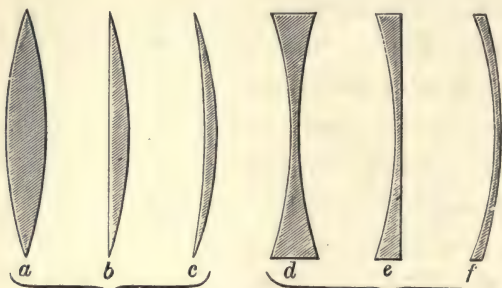


FIG. 267.

‘double concave’ lens, being bounded by two concave surfaces; *e* is a ‘plano-concave,’ and *f* a concavo-convex lens, in which the concavity exceeds the convexity. All diverging lenses are thinnest in the middle.

The straight line drawn through the centre of the lens perpendicular to both surfaces is called the ‘axis;’ the axis obviously passes through the two centres of curvature of the bounding surfaces.

In fig. 265 only the seven rays actually represented could possibly intersect, after refraction, in the point *c*; for a ray from *a*, which falls upon the small prism *b* near the upper edge, would pass after refraction above *c*, while another ray which falls upon the same prism nearer to its base would pass after refraction below *c*. In order to refract these rays also towards *c*, the upper ray would need to be somewhat more, and the lower ray somewhat less refracted, than the middle one, or the

refracting surfaces must, in that case, be more inclined to one another at the top and less inclined at the base than they actually are. Now this is precisely the effect of a spherical lens. Its form permits a gradual change in the inclination of the two bounding surfaces, and if its surfaces are accurately formed, all rays which impinge upon it from a luminous point which is not too close to the lens, and is either in the axis or near it, will converge after refraction to one point.

Incident rays parallel to the axis will converge after refraction to a point f , fig. 268; this point is the *principal*

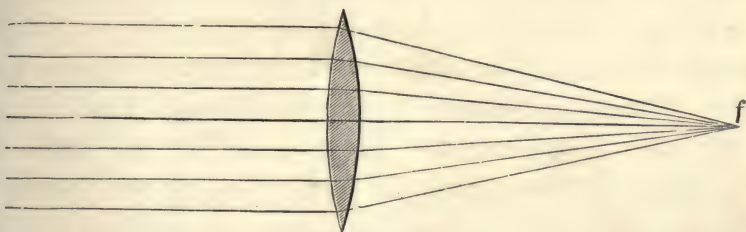


FIG. 268.

focus, and its distance from the centre of the lens is the 'focal length' of the lens. The focal length of lenses does not depend solely on the radius of curvature as is the case with mirrors; it also depends on the kind of glass of which the lens is made. In a common double convex lens, in which the radii of its two surfaces are equal, the focal length is somewhat less than the radius of curvature, while in a plano-convex lens it is somewhat less than twice the radius.

Rays of light which proceed from the focus are refracted so as to pass, after emerging from the lens, in directions parallel to the principal axis; such rays therefore do not again converge in a point.

If the luminous point is nearer to the lens than the focus, as for example the point A in fig. 269, f being

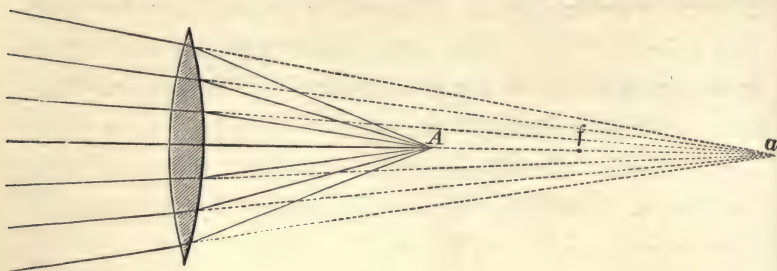


FIG. 269.

the focus, the rays from A will diverge still more, and the lens can no longer render them convergent nor make them parallel after emergence; the rays will still diverge after having passed through the lens, but their divergence will be less than it was before reaching the lens; and the rays from A will, after having passed through the lens, appear to proceed from a point a , farther from the lens than A .

Refraction through lenses, like reflection from mirrors, gives rise to the production of optical images, and the same distinction must be made between real and virtual images; a in fig. 269 is a virtual image of A .

In order to determine the position and magnitude of images produced by lenses, it is not only necessary to know that rays of light which proceed from a point near the axis are refracted so as to converge to a point near the axis, or so as to appear to diverge from that point, and also that rays which are parallel to the axis converge in the focus, while, conversely, rays which diverge from the focus are refracted in parallel directions; but it is also important to consider that those rays which

pass through the middle of the lens retain their original direction, because the two opposite faces of the lens are parallel near the centre, and the rays are therefore refracted twice equally, but in opposite directions. The lateral displacement of the ray (see fig. 259, page 457) may in this case be neglected. This has a sensible effect only if the light falls in a very oblique direction upon glass, and if the thickness of the latter is considerable; but in the determination of the optical images of lenses, only those rays fall under consideration which proceed from points near the axis, and which are, therefore, nearly perpendicular to the middle of the lens.

Let AB in fig. 270 represent an object of which the distance from the lens is twice the focal length, f being

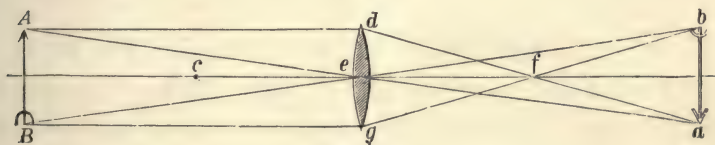


FIG. 270.

the principal focus for rays which proceed from left to right; for parallel rays passing from right to left, the corresponding focus would be in c . The ray Ad , parallel to the axis, is refracted to the focus f , and proceeds after refraction in the direction dfa ; the ray from A which falls upon the centre passes through the lens in the same direction, viz., ea ; both rays meet at a , and in the same point all other rays from A converge: hence a is the image of A . Similarly the rays Bgf and $Be b$ determine the point b where the image of B is produced. The image of AB is thus ab ; it is real, inverted, has the same magnitude as the object, and image and object are at the same distance from the lens.

If the distance of the object from the lens is greater than twice the focal length, as in fig. 271, the image is

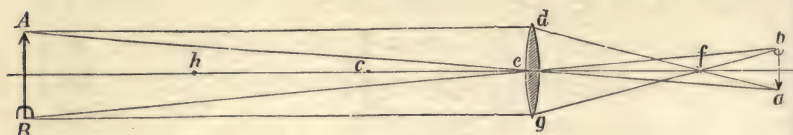


FIG. 271.

smaller; if the distance is less, as in fig. 272, the image is greater than the object. In both cases the

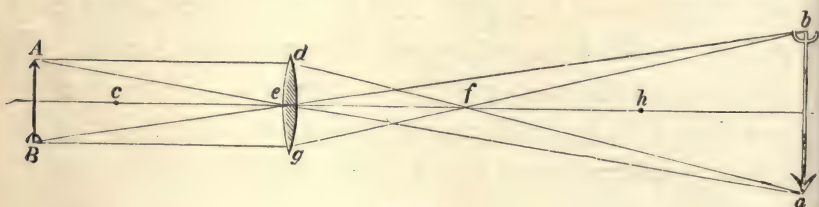


FIG. 272.

contraction which leads to the determination of the position of the images is quite similar to that explained with reference to fig. 270, and the same letters are employed in all three figures for corresponding points.

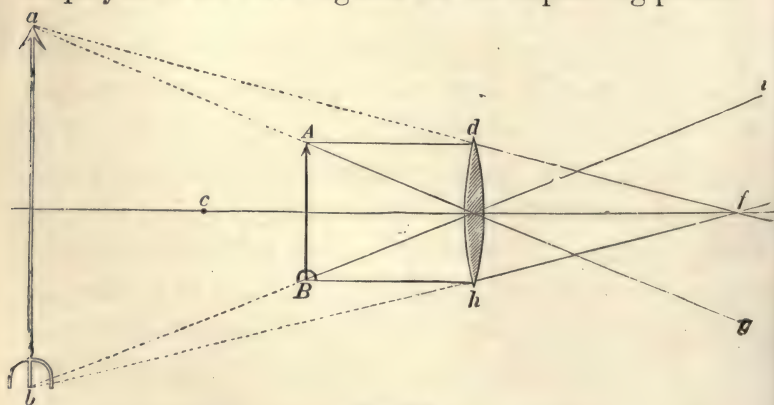


FIG. 273.

Let, in fig. 273, the object AB be between the lens and its principal focus, the latter being denoted by c for

rays passing from right to left, and by f for rays from left to right. The rays $A d$ and $A g$ pass, after refraction, in directions $d f$ and $A g$, which do not intersect but diverge and appear to proceed from the point a ; a is the virtual image of A . Similarly the rays $B h f$ and $B i$ give b as image of B , and consequently the total image $a b$ is virtual, erect, and magnified, and is situated on the same side of the lens as the object. The image can obviously only be seen by an eye which is so placed as to receive the rays after passing through the lens; in the figure the eye would have to be situated on the right side of the lens.

The distance of an image from the lens is calculated by rules which correspond to those given with reference to concave mirrors (see page 448). The magnitude of the image is also found similarly, but in a lens *the magnitudes of object and image are proportional to their distances from the centre of the lens*, while in a mirror they are proportional to the distances from the centre of curvature.

Lenses should have a small curvature if they are to form correct images; the curvature of lenses may however be much more considerable than that of mirrors without producing distortion. The glass of which the lens is made must not only possess the correct outline of a portion of a sphere, but the glass itself must be of uniform quality throughout. The best lenses are very expensive: a single biconvex lens of a superior kind, 6^{cm} in diameter, is worth several pounds, while a common lens of the same size, such as those used for burning-glasses, may be had for a few shillings.

Expensive lenses are principally required for the better kind of telescopes. For the following experiments in which we simply study the different kinds of images produced by lenses, a large lens such as a reading glass, and several smaller ones (for experiments to be described hereafter) are quite sufficient.

In these experiments the diameter of the lens is assumed to be 6^{cm}, the radius of curvature of each surface as 30^{cm}, the focal length

as 28^{cm}; the thickness of such a lens in the middle exceeds that of the edge by about 3^{mm}. Any other lens, not too small nor too convex, will however serve quite as well.

In the middle of a circular piece of cardboard about 15 or 20^{cm} in diameter, of the same thickness as the edge of the lens, cut a round hole of the exact size of the lens, which should just fit into it, neither too loosely nor too tightly. Prepare two rings of cardboard, having an internal diameter somewhat smaller than the lens (5·6 or 5^{cm}·8) and an external diameter of about 9^{cm}. Glue one of the rings round the hole so as to form an edge around it; the edge will project 1^{mm} or 2^{mm} and prevent the lens when placed upon it from falling out on that side. The other ring is placed similarly upon the opposite side of the cardboard, but fastened only with three or four drawing pins, or with a few drops of sealing-wax, so as to be easily removed when the lens is to be taken out again.

For the experiments, the round piece of cardboard with the lens is clamped in the fork of the retort stand, which is turned until the lens is perpendicular. The flame of a candle may again be the luminous object, and the paper screen used in the shadow experiments may serve for receiving the image. The broad edge of the cardboard round the lens serves for throwing a shadow upon the greater portion of the screen on which the image is received, for the bright image appears, by contrast, much more distinct if the neighbourhood is comparatively dark. The lens must in these experiments be *between* the candle and the screen, for the real images formed by lenses are on the side opposite to that on which the object is. Care must also be taken, 1st, that the light be incident upon the lens in the direction of its axis; the candle and the middle of the lens should therefore be at the same height; 2nd, that the cardboard frame of the lens should be at right angles to the straight line from the flame to the centre of the lens. The necessity of these precautions becomes apparent when a well-defined image has been obtained; then the slightest displacement of the lens from the correct position at once impairs the distinctness.

When the lens has a focal length of 28^{cm}, the candle must be at a distance of 56^{cm} on one side of it, and the screen at the same distance on the other side, if the image is to be of the same size as the object. If the screen is moved farther from the lens, the candle must be moved nearer to it in order to produce again a distinct image, which will be magnified. If the candle is placed at a greater distance, the screen must be moved nearer to the lens, and the image will then be smaller than the object. As in the case of a

mirror, a strongly magnified or greatly reduced image may be obtained by projecting the image of the candle flame upon the wall.

If the focal length of a lens is not known, it may be found in the following manner. Place a candle on one side of a lens, about 1^m from it; move the screen on the other side to and fro until a well-defined image of the candle is produced. Measure exactly the distances of flame and screen from the lens, multiply these distances together, and divide the product by the sum of the distances; the quotient is the focal length of the lens. Thus suppose the distance between the lens and the candle is 95^{cm}, that between lens and screen 58^{cm}; we should then have by the rule:—

$$\frac{95 \times 58}{95 + 58} = \frac{5510}{153} = 36.013 \text{ centimetres;}$$

that is, the focal length of the lens is almost exactly 36^{cm}.

A convex lens is often used as a *magnifying glass*, the object being placed between the lens and its principal focus. The image is erect, virtual, and the more magnified the less the focal length of the lens. In our lens, of about 30^{cm} focal length, the image is very little magnified; in the most favourable position the image has not quite twice the size of the object. But a lens having a focal length of 3^{cm} magnifies eight times if held close to the eye, and the object is brought nearer and nearer until a distinct image is seen. A small object is better and more completely seen through such a lens than a larger one; thus in the cross-section of a piece of cane, the tubiform vessels may be distinctly seen by means of such a lens.

The *camera obscura* is a contrivance for obtaining distinctly visible and real images of objects which are not brightly illuminated, as for example common objects in diffused daylight. The principal aim of the apparatus is to exclude all light which does not proceed from the object itself, from the surface upon which the image of the object is received. The 'camera' is especially used in photography. A real image, usually smaller than the object, is received upon a plate chemically prepared so as to render it sensitive to the action of light, and a permanent photographic picture is thus produced; it is, however, usual to introduce into the camera, before

exposing the sensitized plate, a plate of ground glass in order to adjust the lens to the distance required for obtaining a well-defined image upon the plate. The photographic camera is usually a square box, often made of two parts, one sliding in the other, so that the whole may be either shortened or lengthened for the purpose of adjustment. The front side carries a tube in the middle in which the lens is fixed ; at the back there is a frame into which the plate of ground-glass and afterwards the sensitized plate may be placed. Before the latter is introduced the image is first rendered as distinct as possible by directing the lens or ' objective ' towards the object, holding the head at a distance of 15^{cm} or 20^{cm} behind the ground-glass plate, covering the head, and the back of the camera, with a thick black cloth, and then shortening or lengthening the camera until a tolerably distinct image is seen on the plate; more perfect definition is finally obtained by a finer motion of the lens to or fro, which is given to it by a rack and pinion. The objective of a camera does not in reality consist of a single lens, but of a combination of several, which acts in a like manner ; for the mere production of a visible image, a single lens is sufficient, though not for photographic purposes.

On account of the inverted position of the real images it is somewhat inconvenient to observe them ; by a slight modification of the camera, the images may, however, be received on a horizontal surface, and thus rendered more convenient either for observation or for the purpose of copying them by drawing. Such a camera is represented in fig. 274 ; it may easily be made by the student with a little care. The rectangular box

$a b c d e f g$ (in the figure the side $a b c d$ is partly cut away so as to allow the internal arrangement to be seen) has in the front side a tube r , in which another tube with the lens may be moved to and fro with moderate friction. In the back part of the box there is the in-

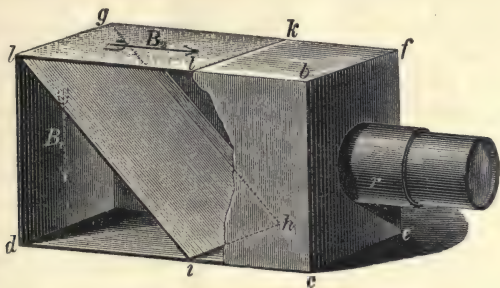


FIG. 274 (*an. proj.*, $\frac{1}{6}$ real size).

clined mirror $a g h i$; the part $a g k l$ of the top of the box is formed of a plate of glass which is either ground or covered with semi-transparent paper. Without the mirror the image produced by the rays which pass through the lens and tube would be at B_1 ; the mirror reflects the rays so that the image appears at B_2 upon the plate of glass. It may be seen conveniently by standing behind the camera, bending the head forward over the glass plate, throwing a thick cloth over head, shoulders, and camera (except the tube), and moving the tube with the lens to and fro until a distinct image appears.

For our lens of 28^{cm} focal length the box should be made 23^{cm} long, and 15^{cm} wide and high. The glass plate (a piece of flat window-glass) should be 15^{cm} long and wide; the portion of the upper side which is not transparent will thus be 8^{cm} long. The mirror which makes an angle of 45° with the back of the box is 15^{cm} wide and 21^{cm}·2 long; it is kept in position by four little strips

of wood or cardboard, 1^{cm} wide, which are glued, a pair to each side of the box, in such a manner as to leave a space equal to the thickness of the mirror between them; the mirror is pushed down from above into the frame thus formed, before the glass plate is fixed. The box may be constructed of wood or stout cardboard; the tubes must in any case be made of cardboard. With the help of a round piece of wood, 6^{cm} in diameter, form a tube 10^{cm} long, into which the lens will just fit; a second tube only 5^{cm} long is formed over the first, so that the inner tube may move with moderate friction within the outer one; one end of the short tube is glued into the front of the box, so that the tube may project outwards. The lens is fixed in the outer extremity of the inner tube between two rings of cardboard, which are formed by bending strips 1^{cm} wide and about 18^{cm} long; one of the rings is glued into the tube so that the end of the tube projects about 1^{cm} beyond the ring; the lens is placed against the edge of this ring, and pressed firmly against it by the second ring, which should fit so tight into the tube as to remain firm by friction alone. It will thus be possible to remove the lens again easily if it is wanted for other purposes.

The interior of the inner tube and box should be covered with rough black paper. The glass plate should be covered with semi-transparent paper; either common paper if it is desired to copy the images with pencil, or tissue paper of the kind used for the screen in Art. 38, if the images are to be merely looked at.

Concave lenses may be considered as composed of a number of small prisms which have their refracting edges turned towards the middle of the lens, in the same manner in which convex lenses may be considered as made up of prisms which turn their refracting edges away from the centre. It follows that concave lenses will refract light so as to cause it to diverge from the axis of the lens. Light incident upon a concave lens parallel to the axis is refracted so as to diverge, after passing through the lens, as if the light proceeded from a point *f*, fig. 275. This point is the principal focus of the lens, and may be designated as the point of divergence or negative focus; its distance from the lens is the focal

length of the latter, generally denoted by a negative sign, so as to distinguish between the action of the two

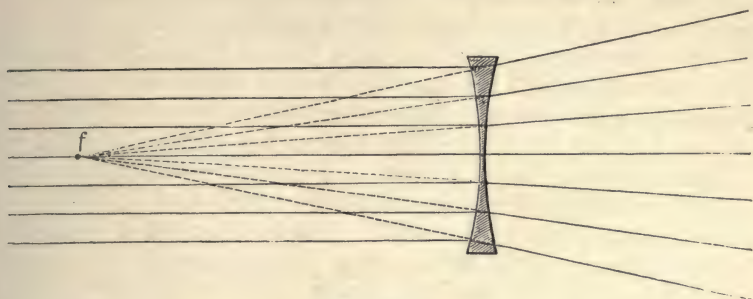


FIG. 275.

kinds of lenses, viz., converging or convex, and diverging or concave lenses.

A concave lens produces always a virtual erect image, smaller than the object, whatever the distance of the object. Fig. 276 serves to explain the formation of such an image. The ray $A c$ from A proceeds, after having passed through the lens, in the direction $c d$, as if it originated in f ; the ray $A e$, through the centre of the lens, passes to g without changing its direction; $c d$ and

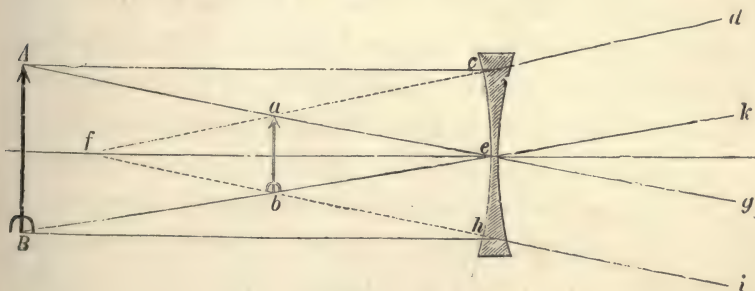


FIG. 276.

$e g$ appear both to come from a : hence a is the image of A . Similarly b is the image of B , as seen by tracing

the path of the rays Bhi and Bek ; thus ab is the image of $A B$.

The reduced virtual image produced by a concave lens can only be seen by looking through the lens at the object, in the same manner in which the magnified virtual image formed by a convex lens is seen, when object and image are on the same side of the lens. The image is the more reduced, the smaller the focal length of the lens. Spectacles used by short-sighted persons are concave lenses; the images which they produce appear to a good eye smaller than the objects, especially if the lenses are made for very short-sighted eyes, that is, if they are very concave. The focal length of spectacle glasses is usually a few decimetres, so that the image is not very much reduced. For the experiments which are hereafter to be made with reference to the explanation of the action of the telescope, a concave lens of 6^{cm} focal length is required, which produces an image considerably smaller than the object.

41. *Dispersion of Light. The Spectrum.*—The appearance of colours has been already alluded to in describing the action of the water prism in the preceding article; the same phenomenon is also rendered visible, although in a smaller degree, by a glass lens. A pencil of light which has passed through a prism does not form a white spot upon a screen, but one striped with colours; objects viewed through prisms appear with indistinct and coloured outlines; images produced by lenses have similar coloured fringes, although the coloured part is usually narrower than in the case of prisms. The cause of this is that common white light is a mixture composed of light of various colours, each colour being refracted differently from any other. The greater the deviation from their original path of the rays which have passed a prism, that is, the greater the refracting angle of the prism, the more separated are the different colours: the band of colours is wider if the prism has a refracting angle of 20° than

when the angle is only 10° . But the substance of the prism has also an essential influence upon the extent of the coloured space. A water prism with a refracting angle of 15° produces about the same deviation as a glass prism with a refracting angle of 10° ; an object seen through either prism appears equally displaced from its true position, but the coloured fringe produced by the water prism is less broad than that produced by the glass prism: the difference in the deviation of the various colours is greater in the glass prism than in the water prism, or, as it is termed, glass effects a greater 'dispersion of light' than water. Even different kinds of glass produce different amounts of dispersion; thus *flint-glass* possesses nearly twice the 'dispersive power' of *crown-glass*. A liquid substance called *Carbon Disulphide* has a still greater dispersive power than flint-glass; a prism filled with this substance, and having a refracting angle of 45° or 50° , is therefore especially well adapted for experiments on dispersion.

A suitable form of such a prism is shown in fig. 277, *A*; a section of it is represented in *B*. A portion of a lamp cylinder *c c c*, cut obliquely at both ends, is closed by glass plates *pp*₁ and *pp*₂, and has on the upper side an aperture, to be closed afterwards, for pouring in the liquid.

If such a prism, which produces a deviation of from 32° to 38° , be held with its refracting edge downwards in the path of the rays of sunlight which fall through a window, the rays will be refracted upwards, and will produce on the opposite wall not a white spot with a coloured fringe, but a band of colours in which no longer

any white light appears : this coloured band is called a *spectrum*. The colour which is least refracted and appears therefore lowest in our spectrum is the red ; the uppermost colour, which is most refracted, is the violet.

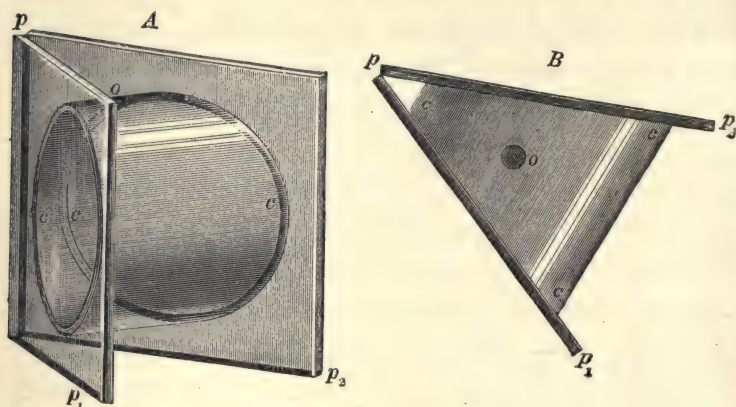


FIG. 277 (*A*, an. proj. ; *A* and *B*, $\frac{3}{4}$ real size).

The prism should be made of the wider part of a lamp cylinder ; a broken cylinder may be used, as only a short piece is required. First draw with ink the two lines which form the edges of the prism at each end, and along which the cylinder is to be cut, taking care that the two ellipses thus drawn appear each as one line, if seen by an eye kept in the same plane, and also that their inclination be that in the figure shown at *B*, viz. 45° , so that the refracting angle may have the desired magnitude ; for if the angle is too small, the spectrum is too short, and if the angle is too great no spectrum is produced, because in that case the light does not emerge from the second refracting surface, but is reflected backwards. When the lines are quite dry, a crack from the edge is made with pastille and carried round along the line ; the same is done at the opposite end. The edges must be carefully ground with emery-powder upon an iron plate ; but, before this is done, the hole for filling the prism with liquid should be bored with a file, for otherwise, if the glass should break while the hole is being made, the labour of the grinding would have been thrown away. The plates which form the refracting edges must be made of perfectly flat plate glass, or the prism is nearly useless. If such glass cannot easily be obtained, the silvering

should be scraped from some pieces of looking-glass (preserve the substance scraped off for electrical experiments). The plates need not be more than about 1·5 or 2^{mm} thick, but it does no harm if they are thicker, except that very thick glass is difficult to cut with pastille; in any case, however, it is best to have the plates cut square by a glazier and simply to round off the edges upon a grindstone. The width of the plates should be about 1^{cm} greater than the diameter of the cylinder, and the length at least 1^{cm} greater than the longest diameter of the elliptical opening which they are to close; but, as the length needed to make their edges exactly meet at *p* depends on the width of the narrowest part of the ground cylinder, it is best first to cut pieces of cardboard to the proper shape, and fit them so that their edges may touch one another properly, as in fig. 277, *B*, and then have the plates cut to the same size.

The well-cleaned plates are placed one on the other and joined along one of their short edges by a strip of thin paper glued upon both; this forms a hinge convenient for giving to the plates their proper position, and may afterwards be removed again. When this band of paper has become pretty stiff, one plate is raised by taking hold of the other short side, the second plate remaining on the table, and the cylindrical piece is inserted between them; the plates remaining in contact with the ground edges of the cylinder, the proper position is found, and holding the cylinder with one hand, the upper plate is turned back, the edge of the cylinder covered with glue, and the plate pressed rather firmly but cautiously upon it, taking care not to displace the cylinder. The glue should not be too thin, so that it may become firm as soon as possible; a very thin layer should be laid on the edge with a fine camel's-hair brush; care must be taken that nothing is smeared inside the cylinder, nor much squeezed into the inside when the plate is pressed upon the edge. When the glue has become firm, after a few hours, the whole is cautiously raised, turned over so that the plate that has been fixed now rests on the table, and the other plate is fixed in the same manner. The thin layer of glue generally contracts in drying, and leaves chinks between the edge and the plate. The joint should therefore be made perfect by the following cement, which never becomes quite dry and is impenetrable for the carbon disulphide. Break 10 grammes of glue into small pieces, and soften them for a few hours in cold water; pour the water off, and add 10 gr. of common brown treacle; heat the whole cautiously in a small tin can, stirring continually until the glue is dissolved and both substances are thoroughly mixed.

Let it boil a few moments and then cool, until all bubbles in the mass have disappeared. Heat again cautiously until it is a thin liquid, but do not boil, lest bubbles should again form. Of this liquid spread a thin layer with a small brush along the joint, and repeat this every few hours until a layer is formed all round a few millimetres thick.

The moisture of the glue evaporates partly into the cylinder, and a thin film of vapour is usually formed within. This may be removed by introducing into the hole of the cylinder a thin tube, which reaches to about the middle of the space within, and then sucking strongly at the end of the tube; the renewal of the air inside thus produced causes a rapid evaporation of the film of vapour.

Carbon disulphide emits a peculiar fetid odour, evaporates very easily, and is an extremely inflammable liquid, heavier than water, with which it does not mix; it is therefore often preserved under a layer of water. Resinous substances are dissolved by it; for this reason sealing-wax cannot be used for fixing the plates. Care should be taken to have no flame nor glowing bodies near this liquid whilst working with it; a mixture of its vapour with air is quite as dangerous as one of hydrogen and air.

The carbon disulphide cannot be drawn from the bottle by means of a pipette, or the pungent vapour would then enter the mouth. If it should have been preserved under water, fill the bottle completely with water so that all air is driven out, close the mouth of the bottle with the thumb, invert the bottle, and, when all the water has ascended to the top, allow the carbon disulphide to escape slowly from the bottle by cautiously removing the finger from the mouth, while holding the neck of the bottle within a large funnel. The air must, previously to inverting the bottle, be driven out completely, for if there remains a space above the liquid filled with air the space will also contain a quantity of the vapour of the carbon disulphide, which exerts a considerable pressure and would cause the liquid to be squirted about when the finger is drawn aside. The funnel should contain a suitably cut filter for retaining any admixtures of water and other substances suspended. This funnel is fixed into an arm of the retort-stand; another arm, attached to the stand below this one, carries a smaller funnel, so arranged that the liquid may flow from the larger funnel into the smaller, and from the smaller into the prism, into the interior of which the tube of the smaller funnel reaches. If the tube of the smaller funnel is too wide for the hole in the prism, draw out a glass tube, insert the thin end into the prism and the funnel tube into the wider part of this tube. Care must be taken that the liquid escapes very slowly from

the bottle into the funnel, to prevent its running over the rim of the smaller funnel. The prism must not be filled completely, but a space of a few cubic centimetres should remain empty ; if quite full, it is difficult to close the aperture. This is done by placing a layer of the above cement, very thin and about 2^{mm} wide, round the aperture, and upon this, after the cement has cooled but is not yet stiff, a small piece of glass, about 1^{cm} square, is firmly pressed. Whether the prism is tight may be judged by the absence of smell if all carbon disulphide is removed from its vicinity. If no smell is perceived, the piece of glass is covered several times with layers of the cement and allowed to dry during several hours before it is handled.

If the prism during the filling in is seen to leak, the liquid must be poured back into the bottle, the prism allowed to dry thoroughly, and any leaky places must be covered again with the cement of glue and treacle.

The whole work is better performed in the open air ; the smell is, however, very soon got rid of if the windows are opened after the prism is filled.

If the work has been successful, the prism will have scarcely a trace of smell, and a diminution of the liquid by evaporation will not be perceptible for years. If it is to be cleaned and refilled, the small glass plate may be removed with a knife, the liquid should then be poured out and the prism placed in water to soften the glue, so that the plates may be removed without too much force.

The prism should be kept in the dark when not in use, for pure disulphide of carbon, which is colourless, assumes a yellowish tinge by the action of daylight, especially direct sunlight. The yellowish liquid commonly sold is not suitable for our purpose ; the student must procure the chemically pure substance.

If a white object on a dark ground is looked at through the prism, or a dark one on a bright ground, as for example a window sash, it appears so much displaced that at first there is some difficulty in finding it ; when found it presents itself surrounded by very broad beautifully coloured bands.

White light consists of a mixture of variously coloured rays, which combined produce the sensation of white light. If the differently coloured rays which impinge upon the prism were all equally deflected from their original path, they would reach the wall after

refraction in the same manner as they were disposed originally, and would produce a white spot. But the violet rays are more refracted than the green rays, the green rays more than the red; hence, if the refracting edge of the prism is turned downwards, as has been assumed in the previous experiment, the violet spot produced by violet rays will appear somewhat higher than the green spot produced by green rays, and the green again higher than the red. The spectrum is nothing else but a succession of variously coloured spots or bands of light, each representing a distinct and definite colour. A single colour, however, is seen only at the ends of the spectrum—at the lower end red, and at the upper end violet: in the whole intermediate space the bands overlap one another partly, and each portion of the spectrum presents a mixture of several adjoining differently coloured rays.

When the water prism with small refracting angle is used, the dispersion is so inconsiderable (that is, the coloured components of white light differ so little in the amount of deviation which they undergo) that the spots illuminated by each colour almost coincide, the refraction of the violet light being very little greater than that of the red; hence only a very narrow violet band is seen on one side of the bright spot produced by the light which has passed through the prism, only a very narrow red one on the other side. For the most part, the different colours fall upon the same place, and therefore produce again white light in by far the greater portion of the spectrum. It is obvious that the red band will be above and the violet below, if, as in the arrangement shown in fig. 262, the re-

fracting edge is directed upwards, and therefore the deviation takes place downwards.

Strictly speaking, the spectrum of white light is composed of an infinitely great variety of colours, each one being very little different from the next in order of succession ; although a sharp separation is thus impossible, on account of the gradual transition of one colour into the next, certain principal groups have been distinguished by the following names, beginning with the colour of the least refrangible rays :—

Red
Orange
Yellow
Green
Blue
Indigo
Violet

If a spectrum produced by the carbon disulphide prism above described, be received on a wall 2^m distant, the dispersion would lengthen a spot 5^{cm} in diameter to a band 20^{cm} long and 5^{cm} wide, in which the single colours still overlap for a space of nearly 5^{cm}, so as to produce a mixture in the middle.

A purer spectrum is obtained if a narrow slit instead of a circular aperture is interposed in the path of the rays before they reach the prism. This may be accomplished in various ways, and it is then best to view the spectrum direct—that is, to look through the prism at the slit.

A slit, 5^{cm} long and 5 or 6^{mm} wide, may be cut in the middle of a large sheet of pasteboard not less than

50^{cm} square. The sheet is fixed with a few tacks to the upper part of a window, the slit being horizontal. A retort-stand is placed on the table so that an eye situated near and above the arm of the stand may see the light of the sky (and the sun) through the slit; the prism is then supported by the arm of the stand, its refracting edge downwards, and the eye applied to it. The window and the sheet of pasteboard will appear to be much lower than they really are, and in the place of the slit a beautiful spectrum will appear, red at the uppermost end, violet at the lowest. The deviation caused by the carbon disulphide prism is so great that the eye must be directed downwards in looking through the prism, in order to see the slit and the sheet of pasteboard. In the spectrum on the wall the violet was uppermost, but a little consideration will show why in the present case the spectrum presents the colours in an inverted order. We have already seen in the last article that objects appear displaced upwards if the prism deflects the rays of light in a downward direction; it follows that in the present position of the prism, in which the light is refracted upwards, the slit must appear displaced downwards, and the more so the greater the amount of refraction. Now, if red light alone were to pass through the slit, we should see a red image of the slit instead of a spectrum; if only blue light passed through the slit, we should see a blue image, displaced more downwards than the red. This difference in the relative positions of the various colours can be studied by covering the slit with red or blue glass, though this method is only imperfect, for coloured glass does

not transmit light of only one colour, but always a mixture of various colours, each of which has a different refrangibility ; thus blue glass transmits mostly blue rays, but also some that are green and violet, and even a sensible quantity of red rays. If, therefore, blue glass is interposed between the slit and the prism, no distinct blue, but an indefinite band, presents itself when the slit is viewed through the prism, the colours extending from green to violet with a reddish tint somewhat beyond the edge. It is, however, possible to show in another way that the coloured spectrum which a bright object (a slit, a flame, &c.) presents when viewed through a prism is really produced by seeing the body in various colours placed side by side. For this purpose a hydrogen flame is used, to which, by introducing various substances into it, different colorations may be given.

For these experiments the gas-generating apparatus in fig. 156 is used. An india-rubber tube is attached to the stopcock *h*, and the other end is drawn over the mouthpiece of a blowpipe, so that the gas may issue through the fine aperture. The blowpipe is clamped horizontally in the retort-stand by its longer end, the fine aperture being directed upwards, so that the flame is perpendicular. Before attaching the blowpipe, the gas must be carefully tested for its purity, as in the case of the experiments with the chemical harmonicon. For the experiments to be described, hydrogen should not burn at the end of a glass tube, because the glass by itself, when hot, gives a yellow colour to the flame. Care must also be taken that the aperture of the blowpipe is perfectly clean, as even slight impurities may colour the flame. The latter should be regulated by the stopcock so as to have a height of about 1.5 to 3^{cm}. When several experiments are to be made in succession, the generating apparatus should be previously filled anew.

A platinum wire must be used for introducing the substances into the flame ; other metals do not resist the heat of the hydrogen flame sufficiently well. A platinum wire, from 3 to 6^{cm} long and

$\frac{1}{4}$ mm thick, is bent with the pliers at one end into a small ring, 1 or 2 mm wide, and the other end is fused into a bit of glass tubing. A piece of tube about the thickness of a pencil is drawn out into a point at one end, the point broken off, and the straight end of the wire pushed into the aperture so that about 5 mm are inside the tube. The wire and the end of the glass are then heated strongly over a spirit or gas flame until the glass melts round the wire, and the latter is fixed in it. Fig. 278 shows the wire with the glass handle.



FIG. 278 (*real size*).

The substance to be introduced into the flame is moistened with water or dissolved in it, the ring dipped into it and then cautiously brought near the flame from the side, so that the water may evaporate and the substance become dry. The ring is then held a little higher than the flame until the dry mass is fused and thus firmly adheres to the wire. Not until this is accomplished should the substance be introduced into the flame; the part of the flame to be employed is the lower one, a few millimetres beyond the point of the blowpipe. If the moist substance is brought too soon into the flame, the greater portion is scattered about by the vapour of water formed; hence gradual heating is necessary. The glass tube with the wire may also, for greater convenience, be placed between the cork lining in the clamp of the retort-stand, without great pressure, so that it may be taken in and out without the necessity of turning the screw. The clamp should of course have the requisite height for keeping the ring of the wire, when the tube is clamped, in the most suitable part of the flame.

Many salts which are volatile when exposed to the heat of the hydrogen flame are capable of giving a distinct colour to the flame, which in each case is due to the vapour formed by the substance at this high temperature. Common salt is very easily volatilised, even to some extent at the lower temperature of the spirit-flame; a few small grains of salt sprinkled upon the wick of a spirit-flame or introduced on a platinum wire colour the flame distinctly yellow. For our present purpose a spirit-flame is however not available, as it is

too large and not hot enough for other substances besides common salt.

A few grains of common salt are slightly moistened with water on a watchglass or any small piece of clean glass; the platinum ring is then filled with the moist salt and gradually brought into the flame; a transparent bead will be formed on the ring when the salt is fused, which evaporates pretty rapidly, colouring the flame strongly yellow. As long as there is any salt left on the ring, the flame appears much larger than it was before introducing the salt. The reason is, that the common hydrogen flame is so little luminous that only the hottest part in the middle of the flame can be seen; but the vapour of the salt is so luminous that the outer less hot portions of the flame are also rendered visible.

In order to view the flame through the disulphide of carbon prism, the latter should be placed upon a support formed of wooden blocks, books, &c., so as to have the same height as the flame, with its refracting edge in a vertical position, as shown in fig. 279. It is im-

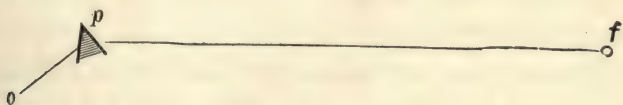


FIG. 279 ($\frac{1}{16}$ real size).

material whether the refracting edge is on the right or left of the observer; the position of the spectrum will in one case be simply the reverse from what it is in the other case. In the experiments described, the refracting edge is supposed to be to the left of the eye; hence the red will appear at the right end and the violet at

the left end of the spectrum seen. The distance of the prism from the flame should not be less than 1^m. By means of fig. 279, it will be more easy to find the direction in which the flame is seen; the latter is denoted by f , the prism by p , and po is the direction of the ray which reaches the eye. When the prism is turned slightly to and fro, its refracting edge remaining in the same position, the deviation will somewhat vary; this follows from what has been stated on page 462; it is best to give that position to the prism in which it produces the least deviation.

The image of the flame when the latter is coloured by common salt appears laterally displaced, but in all other respects it is like the original when viewed without the prism: the hot vapour of the salt emits only yellow light of a definite refrangibility which is the same for all its rays; hence all its rays are equally refracted, and reproduce an undistorted image, just the same as if no refraction whatever had taken place. Common salt consists of a gas, chlorine, and the metal *sodium*. It is the vapour of sodium which colours the flame yellow, and as this metal is contained in a great many substances—for example in common soda, in Glauber's salts, in most kinds of glass, &c.—all these substances when heated in the hydrogen flame colour the flame yellow. Of glass only the smallest trace is evaporated, but this is quite sufficient to produce the characteristic yellow colour.

Another substance, *lithium*, emits in the state of vapour light of a beautiful carmine colour, which also has only one refrangibility. If a small quantity of some compound of lithium—for example, lithium carbonate

or lithium chloride—be introduced into the hydrogen flame, the image of the red flame as seen through the prism will appear as distinct as the sodium flame, but its deviation will be less; that is, it will appear not so far to the left as the sodium flame. Lithium compounds purchased of the dealers contain generally slight admixtures of sodium compounds, and if such a compound, or a mixture of a lithium salt and a sodium salt specially prepared for the purpose, be introduced into the flame, the coloration when viewed with the naked eye will not appear so beautifully red as when the lithium salt is free from sodium. But if such a flame be observed through the prism, two distinct images of it will be seen, one by the side of the other, one having the red colour of the pure lithium flame, the other the yellow of the pure sodium flame. If a mixture is employed which contains more of the salt of sodium and less of that of lithium, the flame will appear to the eye without prism simply yellow, but viewed through the prism two distinct images will still appear, of which the red one, however, disappears sooner than the yellow, because the lithium compounds are more volatile than those of sodium, and the small quantity of the former is thus very soon volatilised.

The eye is incapable of separating the two distinct images which in the above experiment are due to each kind of light emitted by the same flame; and whenever light is compounded in this manner, the eye sees a colour which is in reality a mixture of those present in the source of light. But the prism separates each kind of light from the other by refracting one kind more than the other, and produces thus as many distinct

images of the flame as there are different colours emitted by the flame.

The vapour of *calcium*, a metal contained in lime, colours the hydrogen flame orange. Calcium chloride is best adapted for our experiment because it is, of all calcium compounds, the most volatile; it may easily be obtained in a soluble form by dropping slowly a little hydrochloric acid diluted with water upon a small quantity of scraped chalk in a watchglass. The orange colour of the calcium flame is, however, not simple; it is a mixture of orange and green, as may be easily seen when the flame is viewed through the prism; a green and an orange-coloured image appear by the side of one another.

When a mixture of some lithium salt, a little common salt, and a few drops of the calcium chloride solution, is made with a splinter of wood or a glass rod, and introduced into the flame, the latter appears to the naked eye like the flame produced by the calcium chloride when alone in the flame. This appearance of the flame is shown on the right side of fig. II. (see the coloured Frontispiece); on the left side are represented the four separate images seen when the flame is observed through the prism. The two calcium flames are smaller than the two others, because the compounds of calcium are less volatile than those of sodium and lithium, and are really vaporised only in the inner part of the hydrogen flame.

These experiments are best performed in the evening, or at any rate in a darkened room, for optical phenomena are only well seen when all stray light is excluded. Under any circumstances a dark cloth or blackened sheet of cardboard should be placed a few decimetres behind the flame, so that the latter may be seen on a dark

background. The sheet may be blackened with lampblack ; this is mixed with a thin size made of water and glue, but there should only be sufficient glue to produce a dull black. As the lamp-black is not easily moistened by water, it should be first wetted by a few drops of spirits of wine, rubbed with the latter into a stiff paste, which is afterwards made thinner with a little water, and then mixed with the size, in which the glue must be dissolved while warm.

Common salt and lithium salts volatilise without residue when pure ; calcium chloride leaves a residue of lime behind which may be removed by dissolving it in dilute hydrochloric acid. It is best to keep the platinum wire in a little bottle filled with hydrochloric acid ; a hole is bored through the cork, in which the glass handle fits tightly, and when the wire tube is required it is simply drawn out while the cork is left in the neck of the bottle. Before using it the wire is each time well washed with a jet of water from the washing bottle. Compounds of sodium are contained in small quantities in a great many substances, and the smallest trace of sodium is sufficient to give a yellow colour to the flame. The calcium chloride prepared in the manner above described contains also an admixture of sodium, and without the addition of common salt the yellow sodium flame will make its appearance between the green and orange calcium flame. But if only a small quantity of the calcium chloride is placed on the wire, and it is left for some time in the flame, the sodium salts evaporate, and the residue of lime, although it produces a fainter coloration than the calcium chloride, gives two images, one green and the other orange, due to the calcium flame, while the yellow sodium flame is now absent.

Potassium carbonate may be employed instead of lithium carbonate ; but the image of the flame is neither so beautifully red nor so distinctly visible as the lithium flame, while its deviation to the left is somewhat less than that of the latter. Cigar ashes contain considerable quantities of compounds of potassium, calcium, and sodium ; if a small quantity of ash, moistened with a few drops of hydrochloric acid, be held in the hydrogen flame, and the images observed through the prism, the two calcium flames will be seen, between them the sodium flame, and to the left of the orange calcium flame, but somewhat further from it than the lithium flame in our figure, the red potassium flame will appear. Sometimes cigar ashes contain traces of lithium, and in that case five distinct images are seen when the ash is placed in the flame. This must, however, be done by an assistant while the eye of the observer is applied to the prism ; otherwise the small quantity of lithium present will be

volatilised, and the image of the lithium flame will have disappeared before it can be seen.

The separation of the single images is the greater, the greater the distance between the flame and the prism; it should not be less than 1^m, or the images will not appear quite separated, and if the distance can be made greater it is much better. Shortsighted persons should use spectacles or an opera-glass to see the small flames at that distance.

If more substances, capable of colouring the flame, should be introduced into it, the number of distinct images would obviously increase; they would appear so close to one another that each single image could no longer be clearly distinguished; that is, a *continuous spectrum* would be produced, similar to the spectrum which is observed when a beam of sunlight or daylight passing through a slit is seen through a prism. The flame of a candle or a lamp does not give out only one colour, but an infinite number of colours, and hence of images; it becomes thus impossible to distinguish between the individual images, and they merge into one another like the colours of the spectrum produced by direct or diffused sunlight.

The platinum wire itself, when held in a vertical position in the hydrogen flame until it becomes white-hot, produces a continuous spectrum, and likewise every solid or liquid body when at a white heat; only gases or vapours emit light of one colour when heated until they become luminous. The light emitted by the flame of a candle, or a lamp, or a gas flame, is not caused by the glowing vapours, but is due to the infinitely small particles of white-hot carbon which are set free by the decomposition that takes place at a high temperature of the stearine, tallow, oil, coal-gas, &c. During combustion these particles usually disappear, but their existence can be shown by

holding a cold body, such as a piece of metal, in the flame ; the carbon particles which come in contact with the metal are thereby cooled, the further combustion is thus prevented, and they are deposited on the surface of the cold body as ' soot.'

The most important fact that has been demonstrated by the decomposition of light into rays of various colours, in the manner above described, is that the spectrum consists of a series of images of the flame, each of which is produced in a different position from the rest, in consequence of the refrangibility of those rays by which it is formed being different from that of the rays forming any of the other images. For further investigations into the decomposition of light a special kind of apparatus is used, called a *spectroscope* ; the mode of resolving light by means of it is termed *spectrum analysis*.

Spectroscopes intended for more refined investigations present great varieties of construction, and are complicated and expensive. They consist of a train of prisms which considerably increases the dispersion, and of an optical arrangement of various lenses which enables the observer to view the spectrum as through a telescope, instead of using the naked eye. For our purpose a simple spectroscope is sufficient, consisting of a disulphide of carbon prism, a slit, and a box for keeping off stray light.

When a narrow vertical slit is interposed between the source of light and the eye, the whole flame is no longer seen, but a thin line of light, or a number of such lines side by side, if the light consists of various colours. These fine lines will not so easily merge into one another

as the much broader images of the whole flame, and flame and slit may therefore be brought much nearer to the prism, so that we may use our right hand for introducing the platinum wire into the flame without removing our eye from the prism. The box which contains the prism has besides the slit, which is cut into one side, only one other aperture where the eye is applied; hence no light can enter but that which passes through the slit, and the apparatus may therefore be used in daylight if a blackened sheet of pasteboard is placed behind the flame.

A very simple spectroscope, for which our disulphide of carbon prism may be employed, is shown in fig. 280. *A* represents its exterior, and *B* its interior, when the lid of the box is removed. In *C*, *D*, and *E*, a more elegant form of the same apparatus is shown, which may be provided with very little additional expenditure.

The box *kk* of cardboard has four vertical sides, of which one of the shorter sides, in the figure the one on the left, is inclined to the two longer sides, the other short side being at right angles to them. The slanting side contains the aperture *o* for the eye; in the opposite side a rectangle is cut out of the cardboard, 2^{cm} high and 1^{cm} broad, and closed by a plate of glass, *g*. A cover, *d d*, with a rim which reaches about 1^{cm} over the sides of the box, must fit easily, but closely upon it. Inside the cardboard is blackened (see p. 495), and also the outside of the slanting side; the other portions of the exterior may be covered with some coloured paper, to give to the whole a better appearance.

Obtain from a glazier, or cut with pastille, a rectangular piece of plate or window glass, 4^{cm} long and 3^{cm} wide; smoothen the edges upon the grindstone, and cover one side with tinfoil. This is done by laying a little starch-paste upon one side of the glass, placing upon it a piece of tinfoil of the size of the glass, and pressing the tinfoil with a few fingers of the left hand upon it, so as to prevent it from sliding, while the soft tip of the right forefinger is drawn from the centre to the edge of the tinfoil, in all directions, so as to make the tinfoil adhere smoothly everywhere to the glass, and to squeeze out nearly the whole of the paste at the edge; only a trace of the starch should remain, otherwise the tinfoil will not adhere afterwards to the glass. In the tinfoil a cut is made 2^{cm} long, by

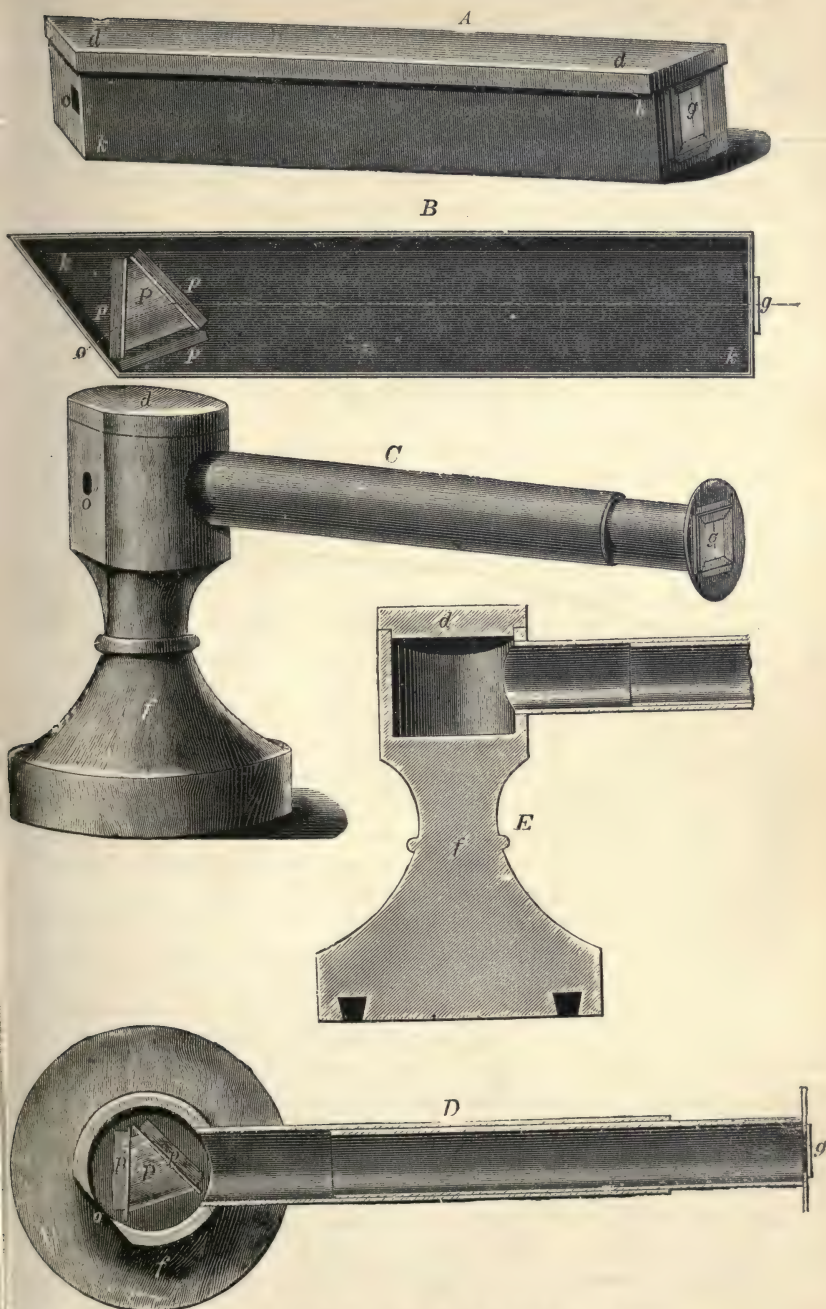


FIG. 280 (*A*, and *C*, *an. proj.*; *A*, *B*, *C*, *D*, *E*, $\frac{1}{4}$ *real size*).

drawing a knife along a small ruler; the cut must be parallel to the longer sides of the glass, and equally distant from either. When the glass plate is held against the light, the cut should appear as a fine line, everywhere equally bright. The glass is now attached with glue over the rectangular opening in the side of the box, by means of four small strips of paper; the side of the plate with the tinfoil being turned towards the interior of the box.

The box must evidently be of the proper size for allowing the prism *P* to be in the position shown at the figure *B*. If the prism has the size assumed in fig. 277, the box must be 6^{cm} high and 8^{cm} wide. The angles of inclination of the slanting side may be taken from fig. *B* with sufficient accuracy. The length of the box should, if possible, be 40^{cm}; if it is shorter, the spectrum will not be so long.

The aperture for the eye is not in the middle of the slanting side, but somewhat to the right of the centre. The proper position for it is found in the following manner. The box is closed, with the lid and the prism placed upon it about in the same position in which it will be afterwards within the box, and close to the slit, at the same height as the prism, a small burning candle is placed. When the eye is brought near to the prism the flame is seen to be drawn out into a spectrum with indistinct outlines. By slightly turning the prism to the right or to the left the position of minimum deviation is found—that is, the position in which the spectrum is least displaced to the left. The eye is then removed a few decimetres from the prism, taking care to keep the spectrum in view. If the prism is small, or the eye rather distant from it, only a portion of the spectrum can now be seen. Now move the head sideways so as to find by trial where the eye must be placed in order to see the yellow portion of the spectrum exactly in the middle of the refracting surface of the prism: the aperture must be made in that part of the slanting side of the box which in this position of the eye is just below the middle of the refracting surface. It should be cut with a sharp knife, 15^{mm} square, as in the figure, or circular with a cork-borer, 15^{mm} in diameter; it should be 3^{cm} from the bottom of the box, when the latter has a height of 6^{cm}, or if the box has a different height from that assumed midway between top and bottom.

The prism is now placed in the box as in *B*, and a burning candle or lamp is placed 4 or 6^{cm} just behind the slit; the slit is next viewed through the aperture, and the prism turned to the right or left until the less bright, but better defined, spectrum of the light which passes through the slit appears least deflected to the left. The position thus found by trial is marked by three strips of pasteboard,

which are glued to the bottom in close contact with the prism, which not only is thus secured in its position, but may be at once again inserted into its right position after it has been taken out.

During use, the box (the lid of course being closed), is placed upon some convenient support, so as to have the flame to be investigated at the same height as the slit.

In fig. 280, *C* to *E*, *f* is a wooden piece to be prepared by a turner; it should have a broad foot 15cm in diameter, and on the top a hollow box, 8cm wide inside, 6cm deep, and the sides should be from 5mm to 10mm thick; the box is closed by a cap *d* (fig. *C* and *E*). The bottom of the box should be about 15cm above the base of the foot. If the prism is smaller than the one in fig. 277, the box may have correspondingly smaller dimensions. If it is intended to varnish or polish the wood, this must be done after the proper place for the eye-hole has been found by the method previously described. The hole is bored 15mm wide, and the outside of the box then made flat with the plane, as shown in the figure, so as to make the edges of the hole very thin. The slit is prepared as above described. The glass with the tinfoil is fixed over the aperture cut out of a round piece of cardboard, 5 or 6cm in diameter, which is attached to one end of a tube of cardboard, of which the other end is glued into a suitable hole in the side of the box. It is very useful to make the cardboard tube of two parts which slide one in the other, each part being 25cm long; the distance between slit and prism may then be altered at will. The narrower tube should in that case be 2.5 or 3cm wide. The proper position of the prism is secured by gluing to the bottom of the box three strips of pasteboard or wood; the interior of box and cap and the portion round the aperture for the eye are blackened, and the tubes lined inside with dull black paper.

It is best to load the foot with lead. To this end a circular groove, a section of which is seen from *E*, is turned into the foot and lead poured into it (400 to 500 grammes). If the wood of which the foot is made is very dense and heavy, it will have sufficient stability, in spite of the projecting tube, without the lead.

A hydrogen flame is best for producing the coloured vapours, on account of its high temperature; where coal-gas is accessible, the flame of a Bunsen's burner may be used, but the spectra obtained are in that case not quite so beautiful.

The spectroscope produces, as has already been mentioned, images of the slit—that is, thin lines of various colours. Thus compounds of sodium give a

yellow, compounds of lithium a *red* line, of calcium an *orange* and a *green* line. The spectra of these substances are represented in fig. I. of the coloured frontispiece. The compounds of potassium impart a pale violet tint to the non-luminous part of the gas or hydrogen flame, but the light emitted by their vapours is partly *red*, partly *violet*, and partly a mixture of the colours of the middle part of the spectrum. The spectrum must hence show a red and a violet line; these two lines are, however, at the extreme ends of the spectrum, and are so faint that they are only seen with difficulty. In our spectroscope only the red line is well perceived, in fig. I. therefore only the red one is shown. For evaporation in the flame, the above-mentioned potassic carbonate, or crude 'potash,' is best adapted; it must be kept in a stoppered bottle because it is deliquescent, that is, it attracts moisture from the air, and dissolves. For the experiments a pretty large quantity should be taken up with the platinum wire, as the salt evaporates easily. Many other substances, for example, the compounds of *strontium* and *barium*, when evaporated in the flame, produce more complicated spectra, which, however, still consist of single lines. Some of these lines are so near to one another, that is, some of the colours emitted by them in the state of vapour differ so little in their refrangibility, that their edges touch one another when viewed through so simple a spectroscope as ours, and they appear as bands with coloured stripes. In the spectrum of strontium especially are to be seen a fine broad *red* band, an *orange* stripe, and a beautiful *blue* line; the latter is only distinctly observed at a sufficiently high temperature, such as that of the hydrogen

flame ; in the Bunsen flame it is scarcely seen. This blue strontium line is really single, and appears so even in larger spectroscopes, but the red band resolves itself when the dispersion is greater into a number of lines of various shades of red. The bands of the barium spectrum show a similar behaviour. Barium chloride, very suitable for the experiments, may be bought at any chemist's. Strontium chloride, the corresponding strontium compound, is not so easily obtained, but strontium nitrate may be substituted, which, on account of its use in making red fireworks, may be readily bought. A very small quantity of it is taken up by the wire, and moistened with hydrochloric acid if the flame ceases to be coloured.

The various compounds of one and the same substance are not volatilised with equal readiness ; the more volatile compound is in general the best for the purpose of spectrum analysis. Besides the six substances above-mentioned only a few more, and those comparatively rare, can be volatilised in the flame of burning hydrogen ; but many other substances, for example, most metals, may be brought to the state of 'incandescent,' that is luminous, vapour by the heat of a powerful electric spark. Many others again—for example, hydrogen itself—which are already in a gaseous state, require the heat of the electric spark in order to be raised to the high temperature at which the light emitted by them is easily perceptible. Every substance, which by any means whatever is brought to the state of vapour (or of a gas), gives out its own spectrum, consisting of definite lines by means of which it may be recognised and distinguished from other substances.

For chemical investigations spectrum analysis is of the greatest importance, especially on account of its delicacy. Each metal, or other volatile substance, gives its own peculiar lines of varied colours ; and when two or more different substances exist in the same vapour the whole of the lines are shown in the same spectrum, each in its own position, for no two metals give lines on the same part of the spectrum. Further, the method is so delicate that a portion of a sodium compound less than the $\frac{1}{2,700,000,000}$ th part of a gramme can be detected, and compounds which were formerly supposed to occur very seldom are by means of this new method proved to be widely disseminated throughout the earth. A still more striking proof of the value of spectrum analysis lies in the fact of the recent discovery of four new elementary bodies by its means, viz. the metals *cæsium*, *rubidium*, *thallium*, and *indium*.

Spectrum analysis has, however, not only been employed by the chemist for the detection and discovery of various substances, but also by the astronomer, for investigating the constitution of the heavenly bodies. If sunlight be allowed to fall upon the slit of the spectroscope, and then received on the wall, or if a slit in a piece of cardboard be held against the window, and the light viewed through the prism, the spectrum is not essentially different from that of a candle flame, or that of every solid or liquid body in a state of white heat; the violet part only will be somewhat larger. Solar light contains more violet rays than that of the flame of the candle or lamp; hence when both are compared, the light of the sun has a bluish, the light of the candle a

yellowish, tinge. But if solar light is more closely observed by means of the spectroscope, a very large number of fine black lines is seen, of different degrees of breadth and shade, which are always present and always occupy exactly the same relative positions in the solar spectrum ; they are called *Fraunhofer's lines* after Fraunhofer of Munich, who was the first to study these lines with much minuteness. The spectroscope used in the preceding experiments exhibits prominently three such lines, in the yellow, green, and blue, one in each colour, as represented in the solar spectrum of fig. I.; but a careful examination shows the whole of the spectrum to be striped, especially in the green and blue portion. The greater the dispersive and optical power of a spectroscope, the greater is the number of dark lines seen in the solar spectrum ; in the largest spectroscopes the number amounts to several thousand. The cause of the striped appearance of the spectrum seen by our bisulphide of carbon prism is, that the lines are too near to one another to be seen single ; only the three lines above mentioned, which are the most marked, appear really as distinct dark lines, while of the others, whole groups, by merging into one another, produce the striped shading of the spectrum as seen by a single prism.

In order to observe the spectrum, the rays of the sun must not be allowed to fall direct upon the prism, for the brilliancy of the light is greater than the eye can bear. The spectroscope should be directed to a wall upon which sunlight is falling, or to the open sky, or a bright cloud. On cloudy days the lower portions of the sky are not sufficiently bright, and as the prism might possibly be displaced if the apparatus were held straight upwards, it is best to fix a small mirror in the retort stand, and to give it by repeated trials a suitable position, so that the light of the sky or of a bright

cloud may be reflected by the mirror horizontally into the spectro-scope. The mirror should first be held in the hand, and by turning it about and looking into the spectro-scope the proper position for it may thus be first approximately found; it is then clamped in the fork in that position, and finally adjusted by turning it and moving the clamp.

The preceding experiments have led to the following results: first, a single colour emitted by an incandescent vapour produces a single image of the slit, that is, a coloured line; second, the continuous spectrum produced by the white hot carbon particles of a flame is an uninterrupted series of all the variously coloured images of the slit which can possibly be produced; third, each single colour has its definite position in the spectrum. It follows from these results, that dark lines must occur in a spectrum which does not include all colours, that is, in which definite colours are absent. The existence of Fraunhofer's lines in the spectrum of the sun is hence a proof that, of all possible coloured rays, some are wanting in the light of the sun.

Since the spectra of all luminous solid and liquid bodies are continuous, and those of incandescent gases consist of single bright lines, we cannot obtain a spectrum intersected by dark lines by merely heating any known body until it becomes luminous. But a spectrum containing dark lines like that of the sun may be obtained if the light emitted by a luminous body is allowed to pass through a luminous vapour, and under these circumstances the remarkable fact is rendered evident that in the spectrum of the solid luminous body those colours are wanting which the interposed vapour emits, by itself, when in an incandescent state.

By holding a piece of lime in the flame of a common

spirit lamp which is fed by a mixture of spirit and ether, and directing a current of pure oxygen upon it, the lime is brought to a state of white heat, and emits a brilliant light, called 'Drummond's lime light.' The spectrum of this light is continuous. If the flame of a common spirit lamp is interposed between the lime light and the slit of the spectroscope so that the rays of the lime light have to pass through the spirit flame before reaching the slit, no sensible change will be perceived in the spectrum of the lime light; but if some chloride of lithium be placed upon the wick of the lamp so that the flame appears red, a dark line will be seen in the red portion of the formerly continuous lime-light spectrum. If now an opaque screen is placed between the lime light and the coloured spirit flame, so that the light of the spirit flame alone falls upon the slit, the well-known red lithium line will make its appearance exactly where the dark line was seen in the spectrum of the lime light when it was viewed through the spirit flame coloured by lithium.

This 'reversion' of lines of the spectrum, that is, the appearance of dark lines in the exact place of bright luminous ones, may be observed by using the light of the sun instead of the lime light. There is no dark line in the solar spectrum corresponding to the position of the lithium line, but if a spirit flame coloured by lithium is placed in front of the slit of the spectroscope, so that the sun's rays have to pass through it a dark line will at once appear in the red portion of the solar spectrum.

This method of reversion is not practicable with a small spectroscope, like that used for the preceding experiments; the dispersion in that case is compara-

tively small, so that the overpowering brightness of the visible portion of the spectrum renders the dark lines invisible. Only larger instruments will give satisfactory results, but another method of reversing the spectrum for which our spectroscope is available will be described farther on.

When a spirit flame coloured yellow by a little salt is placed between the incandescent lime and the slit of the spectroscope, a dark line will appear in the spectrum of the lime light precisely where the yellow sodium line is seen when the lime light is hidden from view by an interposed screen. If sunlight be used instead of the lime light, the sodium line will be seen exactly to coincide with one of the dark lines previously seen in the solar spectrum, and no new dark line will make its appearance in the spectrum of the sun when the yellow sodium flame is between the sunlight and the slit; the corresponding dark line in the yellow will thereby only become darker and more distinct than before the interposition of the sodium flame.

It appears at first surprising that a spectrum which results from a superposition of the continuous spectrum of the white light given out by a solid body, which as we know contains all colours, and the light of an incandescent vapour, which contains one or several colours, should be exactly wanting in the one or several colours given out by the glowing vapour when seen alone. Thus when a lithium flame is interposed so that the rays from the lime-light or from the sun are obliged to pass through it, we should expect as the consequence of seeing both spectra together, that the red portion of the continuous spectrum of the lime or the sun would

contain a particularly bright red line ; but instead of an increase in brightness of a narrow portion of the spectrum, we see the red lithium line to be actually extinguished or a dark line appear in its place.

To explain this, we must consider in the first place, that neither the dark lines in the solar spectrum, nor the dark lithium line produced artificially by reversion, are absolutely black ; they are only less luminous than their vicinity. The human eye is very susceptible to effects of contrast ; a moderately bright object appears much brighter when around it there is comparative absence of light ; and if its neighbourhood is brighter than the object itself, it will appear much darker than it would appear if the object and its vicinity were equally bright. Thus if gradually more light is thrown into the neighbourhood of an object which is moderately bright, the object will appear to become obscured.

This may be shown by Rumford's photometer. Let a burning candle and a lamp be so placed that the shadow of the opaque body produced by the candle, which is at a distance from it of not more than 20^{cm} or 30^{cm}, may be much darker than the shadow produced by the lamp, which is at a much greater distance. If now the lamp be moved nearer to the opaque rod in a straight line so that the shadow keeps the same position, the intensity of the shadow can thereby not be altered, because the shadowed portion continues to receive the light of the candle which remains in its place ; but the lamp throws now more light upon the illuminated part of the screen than before, and by contrast the shadow appears to become darker.

The lines of the solar spectrum and the dark spectral

lines which are artificially produced appear perfectly black when the luminous part of the spectrum is very bright; but they only appear black by their contrast with the bright vicinity; in reality they are brighter than the bright lines produced by incandescent vapour when observed by a spectroscope, as may be proved by experiments, which, however, require large and complicated spectroscopes. The cause of this diminution of light in those lines which appear dark when compared with the remainder of the spectrum, is the property of incandescent vapours, that they are not equally transparent for all colours; incandescent vapours transmit light of all colours completely, except light of the special colour or colours which they emit themselves; these particular rays when emitted by any body whatever are partly *absorbed* in their passage through the glowing vapour.

The yellow vapour of incandescent sodium compounds, for instance, is nearly opaque for yellow rays of the same

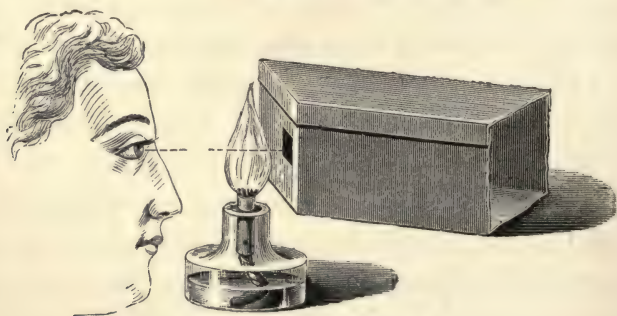


FIG. 281 (*an. proj.* $\frac{1}{4}$ real size).

kind as those which it emits itself, while it is perfectly transparent for every other colour. This may be seen by placing a small paraffin lamp behind the slit, and a

spirit flame coloured strongly yellow by common salt between the eye and our spectroscope, as in fig. 281.

Before the spirit flame is interposed, the bright spectrum of the incandescent carbon particles in the paraffin flame is seen to be continuous. The spirit flame is then placed as near as possible to the aperture of the spectroscope, and the eye brought as near to the flame as can be done without inconvenience from the heat radiated by the flame; in such close vicinity the flame is not distinctly seen, but sheds a yellow tint over everything seen through it, and therefore also over the spectrum produced by the apparatus. The spectrum is still seen, which proves that the vapour is transparent for the various colours, although their purity is naturally somewhat impaired by the admixture of yellow light; but in the yellow part of the spectrum there now appears a dark line in the exact place which corresponds to the position of the yellow sodium line; this yellow colour is therefore not allowed to pass through the sodium vapour, it is absorbed by it; not completely, but sufficiently so to render that part of the spectrum darker than the remainder, or even nearly black by contrast.

The slit should be narrow, not more than 0.2 or 0^{mm}.3, and the paraffin flame about 10^{cm} behind it. The spirit flame must be strongly yellow if the absorption line is to be quite dark. By putting salt on the wick and rubbing it well in with the fingers, the flame will be coloured strongly yellow, but only for a few moments after being lighted; it is therefore better to mix the spirit of wine, before filling the lamp, with about $\frac{1}{10}$ th of its volume of water, throw in half a teaspoonful of salt, and shake the liquid strongly, so as to dissolve as much of the salt as possible. The flame of this alcoholic solution of salt will produce permanent absorption, especially if the flame is from time to time blown out, and the wick rubbed between the fingers. The dark line can only be well seen if the position of

the eye is properly adjusted with reference to its distance from the slit. For this adjustment place a needle horizontally across the slit and fix it with a bit of wax. Look at the spectrum of the paraffin lamp; it will be divided through its whole length into two portions by a black horizontal line; when the eye is so placed that this horizontal line is seen quite distinctly, it is also in the right position for seeing clearly the vertical sodium line.

This mode of reversing the sodium line is not the same as that previously described for the reversion of the solar or lime light spectrum. When the spirit flame is placed between the paraffin flame and the slit, instead of between the prism and the eye, the sodium line is not dark; it is indeed much brighter than the spectrum of the paraffin flame which is seen at the same time. The reason of this is that the quantity of yellow light emitted by the paraffin lamp which is absorbed in its passage through the spirit flame is much less than the quantity of yellow light which the spirit flame emits itself. On the other hand, when the flame is between the prism and the eye, it does not produce a yellow line, but illuminates equally every portion of the spectrum behind it, so that the part which corresponds to the sodium line receives the same light as every other part of the spectrum; hence, if the sodium vapour were equally transparent for every part of the spectrum of the paraffin flame, no change whatever would be observed in any part of the spectrum. But what actually takes place is that the sodium vapour in the spirit flame partly stops the light emitted by a particular yellow part of that spectrum; there appears, therefore, in that place a line which is the darker the more the sodium vapour absorbs of the light given out by the corresponding part of the original spectrum.

When the coloured incandescent vapour, for instance, of sodium or lithium, is between a white hot body and the slit, as in our first reversion experiments, the bright line of the vapour can only appear comparatively dark if the quantity of light given out by the vapour is much less than the quantity of light of the same colour emitted by the hot body which the vapour absorbs, that is, only when the light of the incandescent solid body far exceeds in intensity that given out by the incandescent vapour.

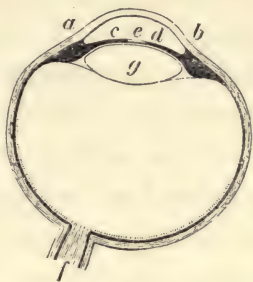
There are various methods of producing continuous spectra which exhibit the dark sodium line; but all agree in this—that very intense light, given out by some white hot solid or liquid substance, is transmitted through the much fainter light of sodium vapour. We may conclude from this that the dark line in the solar spectrum which corresponds to the sodium line is produced in the same manner. It is supposed that the Sun is an intensely hot (probably liquid) body, surrounded by a vaporous envelope which is less hot. That the heat of the Sun must be enormous follows from the fact that this heat is sensible even at vast distances, and that the envelope of vapour must be less hot is a consequence of the constant radiation of heat from the envelope into the surrounding colder space. If the dark absorption line of sodium in the solar spectrum were the only absorption line, the presence of which would be explained by supposing the Sun to be constituted in the manner stated, doubts might be entertained about the correctness of the explanation, although there would be nothing improbable in it. But if the dark lines in the solar spectrum be carefully com-

pared, in powerful spectroscopes, with those of the bright lines in the spectra of certain terrestrial substances (metals), it is seen that each of the *bright* lines of these particular substances coincides exactly with a *dark* solar line; so that if the apparatus be arranged in such a way that the Sun's spectrum and one of these metallic spectra appear one below the other, in the field of the telescope, which in large instruments replaces the simple aperture of our spectroscope, the bright lines of the metal are *all* seen to be continuous with dark solar lines. In the case of metallic iron alone, which may be vaporised by the electric spark, more than 80 bright lines appear in the spectrum of its vapour, all of which exactly coincide with 80 dark lines in the solar spectrum. We may therefore reasonably conclude that our views of the constitution of the Sun are correct, and that, among other substances, the gaseous envelope of the Sun contains vapour of iron.

The same methods of observation and reasoning apply to the determination of the chemical and physical constitution of the atmospheres or gaseous envelopes of fixed stars and other celestial bodies, and spectrum analysis has indeed led, in recent times, to most important additions to our knowledge of fixed stars, nebulæ, and comets.

42. *The Eye. Vision. Optical Instruments.*—The eye has some resemblance, in principle as well as in the arrangement of its parts, with a camera obscura. Fig. 282 represents a horizontal section of the right eyeball. It is nearly spherical in shape, and is composed, in the first place, of a tough firm coating consisting of fibrous tissue, the greater part of which

is white and opaque, and is called the *sclerotic*. In front, however, this fibrous capsule of the eye, though it does not change its essential character, becomes transparent, and receives the name of the *cornea*, *ab* in fig. 282, in which the transparent portion is indicated by two lines only, while the opaque portion is distinguished by a dark shading. The corneal portion of the coating of the eyeball is more convex than the sclerotic portion, as is shown in the figure. Within the sclerotic and in close contact with it is a highly vascular membrane, the *choroid coat*, which is covered with a very black velvety pigment; the choroid coat is indicated in the figure by a rather full black line. In front of the eye the choroid coat passes into the *iris*, *cd*, which is a kind of diaphragm consisting of radiating muscular fibres and having a round central aperture (*e* in the figure) called the 'pupil.' The iris and pupil are seen through the cornea; the former has different colours in different persons. Within the choroid coat, and lining the interior of the eye, is the *retina*, indicated in the figure by a curve consisting of very short lines; it is a very delicate membrane, consisting of a network of extremely fine nerves, all of which proceed from one branch, called the *optic nerve* (*f* in the figure), which enters the eye obliquely at the back of the eyeball. Immediately behind the iris and in contact with it lies the *crystalline lens*, *g*, which has the form of a bi-convex lens of unequal curvature, and is perfectly trans-

FIG. 282 ($\frac{3}{4}$ real size).

parent and strongly refractive. The crystalline lens consists of a fibrous, firm, and highly elastic substance. The case of the eyeball is kept in shape by what are termed the 'humours,' watery or semi-fluid substances, one of which, the *aqueous humour*, is hardly more than water holding a few organic and saline substances in solution; it fills the corneal chamber, while the other, the *vitreous humour*, is rather a delicate jelly than a regular fluid, and keeps the sclerotic chamber full, that is the larger space between the crystalline lens and the retina.

The crystalline lens, together with the concavo-convex space in front of it filled with the aqueous humour, constitutes a compound converging lens of small focal length, which forms of an object in front of the pupil an inverted real image smaller than the object, and projects the image upon the retina precisely as the lens of a camera throws the image upon the ground-glass plate. The network of nervous filaments of which the retina consists is capable of being affected by external agents in such a manner as to give rise to the sensation of light. It is impossible to enter here more fully into the mysterious mode by which that sensation is brought to our consciousness; but so much may be stated, that we have only in that case a distinct vision of any object when the optical image of it produced by the crystalline lens upon the retina is sharp and distinctly defined. If the outlines of the image are blurred, as, for example, in images produced by lenses and received on a screen which is not properly placed, or in the images of a camera obscura of which the tube with the lens is not at the requisite distance from the object, the object appears to the eye dim and indistinct. In the ordinary

camera provision exists for adjusting it to the varying distances of objects: this consists in sliding the lens in and out, and thus changing its distance from the ground-glass plate according as the images of near or of distant objects are to be received on the plate. A similar capability of *adjustment of the eye* enables a healthy eye to accommodate itself to the varying distances of objects and to form distinct images of them upon the retina. Various changes in the eye contribute to this adjustment. The crystalline lens is not only moved forwards and backwards like the lens of a camera, but its convexity is also increased or diminished by the varying pressure of muscles which act upon the edges of the lens, and thereby alter its focal length. If the focal length is thus somewhat increased, the image of a distant object is formed at the same distance from the lens as the image of a nearer object produced by a lens of shorter focal length. Adjustment can take place only within a certain range, which admits of great individual variations. As a rule, no object which is brought within less than 20^{cm} from the eye can be seen distinctly without effort. But in many persons the power of adjustment is limited in consequence of disease or want of practice. Many persons are born with the surface of the cornea more convex than usual, others, (for example, engravers, designers), whose employment necessitates a preponderant application of the eye to near objects, lose the power of adjustment to distant ones; these are *short-sighted*. Others again—for example, seamen—who have mostly to look at distant objects, gradually lose the power of adjustment for near objects. They become *long-sighted*. Elderly people are also usually long-sighted, for as age draws on the cornea

flattens. In short-sighted people the images of objects are therefore formed not on the retina, but in front of it; in long-sighted people objects at ordinary distances are seen indistinctly, because the rays of light strike upon the retina before they have been brought to a focus. The defect of short-sighted people is amended by wearing spectacles with concave glasses, which, combined with the too convex crystalline lens, produce the effect of a less convex lens; long-sighted people, on the other hand, use spectacles with convex glasses, which combined with the too flat crystalline lens produce the effect of a more convex lens.

If a person near a window turns his face to the latter and holds a small mirror before one eye, so as to see the reflected image of the eye, which at the same time receives a large quantity of direct light from the window, the pupil of the eye will appear rather small, and the iris will form a comparatively broad ring around it. If the face is now directed towards the room and the eye again observed in the mirror, the pupil will appear much larger and the iris contracted to a narrow ring. The iris thus takes the place of a self-regulating diaphragm, whose function it is to dilate the aperture and admit more light when the light is weak, but to contract the aperture and admit less light when the illumination is too strong. If the quantity of light which enters the eye were not capable of being regulated in this manner, objects in faint light would fail to make a sufficiently strong impression upon the retina, while, in strong light, the retina would be excited so much as to render all objects too dazzling for clear vision.

When an object is seen, the eye is involuntarily

turned straight towards it, so that the image of the object is formed on a point of the retina which lies at one end of a straight line joining the body and the retina, and traversing a particular region of the centre of the eye. This straight line is called the *optic axis*.

The nearer to the eye an object is situated the larger is its image upon the retina, and the larger does it appear to us. The distinctness of the visible object increases also with its apparent size, provided that its image on the retina is sharp and distinct. On an average the greatest distance of distinct vision is about 25^{cm} from the eye; beyond this distance images of objects appear smaller and therefore less distinct; at a less distance, on the other hand, the image becomes blurred and the object therefore indistinct. To a short-sighted eye an object is still sharply defined at a less distance than 25^{cm}, and such objects appear therefore larger and more distinct than others at a greater distance, while a long-sighted eye sees an object distinctly only at distances beyond 25^{cm}, and the objects appear therefore smaller.

Microscopes and *telescopes* are 'optical instruments,' used for making near or distant objects appear larger or more distinct than they do when seen with the naked eye. The lens described on page 475 is a magnifying glass: when the lens is held close to the eye, a magnified erect virtual image is produced of an object placed at the proper distance; and if the focal length of the lens is known, its magnifying power may be found by adding the 'distance of distinct vision' (25^{cm}) to the focal length, and dividing the sum by the latter. Thus a lens of 10^{cm} focal length magnifies $\frac{25 + 10}{10} = 3.5$ times;

a lens of 6^{cm} focal length produces an image which is $\frac{25 + 6}{6} = 5.166$ times as large as the object. In order

to obtain a greater magnifying power, *compound* microscopes are used, which consist of several lenses arranged within a tube. We must confine ourselves here more to an explanation of the principles of such instruments than to an actual description of their details. Their construction is therefore assumed to be somewhat more simple than it actually is in instruments of that kind. The lenses used in such instruments are not simple, as assumed in our description, but mostly systems of lenses, that is, combinations of several lenses which together produce the same effect as a simple lens, but render the image much more distinct and precise than could be done by a simple lens. Moreover, an apparently single lens in such an instrument consists often of a combination of two lenses, each of a different kind of glass, differing in dispersive power, and so combined as to free the images as much as possible from the coloured fringes which surround objects when seen through simple lenses. Such compound lenses are called *achromatic*.

The Microscope (fig. 283) has a foot *f*, upon which is fixed perpendicularly the pillar *s*. This carries the 'stage' *t*, a horizontal plate perforated in the middle, upon which the objects to be observed are placed between the glass plates *o*, the object being over the aperture in the stage, so that diffused daylight or the light of a lamp or candle may be reflected to it by the moveable mirror *b*. When, owing to the opacity of the objects, they cannot be lighted in this manner from

below, they are lighted from above by means of a condensing lens so placed that the object is in its focus.

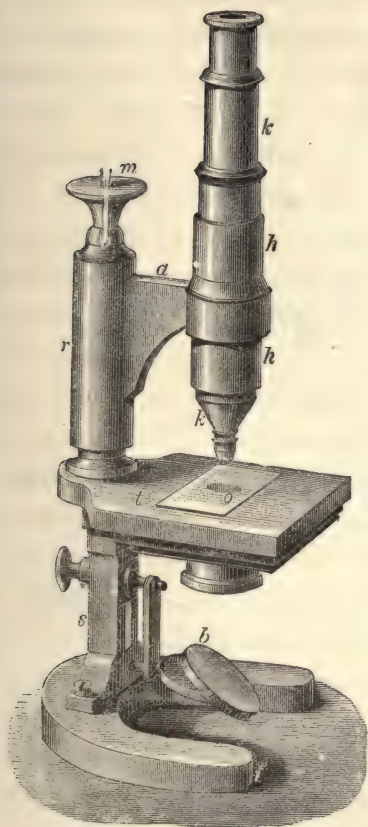


FIG. 283 ($\frac{1}{3}$ real size).



FIG. 284.

The body of the microscope consists of the tube $k k$, which carries at its lower end a lens of very short focal length (usually only a few millimetres), while the eye-

piece consists of a larger lens of greater focal length (a few centimetres). As the objects to be observed vary in thickness, the tube kk must be capable of being raised and lowered. For this purpose it slides with gentle friction in the tube hh , and can thus be approximately placed in the proper position by the hand. In order to give to it a finer motion, the tube hh is fixed by the horizontal arm a to the cylinder r , which may be raised or lowered through a small space by turning the milled head m of a fine screw either to the right or to the left. Fig. 284 explains the mode of action of the instrument. The arrow ab represents the object, c the object lens, of which f_1 is one focus, while the other is at the opposite side near ab . Since the distance of the object from the lens c is less than twice the focal length, the lens produces a strongly magnified image a_1b_1 , the position of which is found exactly as in fig. 272, by drawing two rays from each extremity of the object ab , one ray parallel to the axis, the other through the centre of the lens. This image is seen through the lens de of the eye-piece, which has its focus at f_2 . For this lens the image a_1b_1 is now the luminous object, and being at a less distance from the lens than the focal length of the latter, a magnified virtual image a_2b_2 is produced, which may be found in the same manner as that in fig. 273. It is the image which is seen by an eye looking vertically downwards into the microscope. The images, a_1b_1 and a_2b_2 are inverted with respect to the object. The eye-piece of a microscope acts exactly like a common magnifying-glass.

The construction of a good microscope can only be undertaken by a skilled optician; and as the grinding and adjustment of the lenses

require much time and labour, a good microscope is an expensive instrument, which should only be purchased if required for real

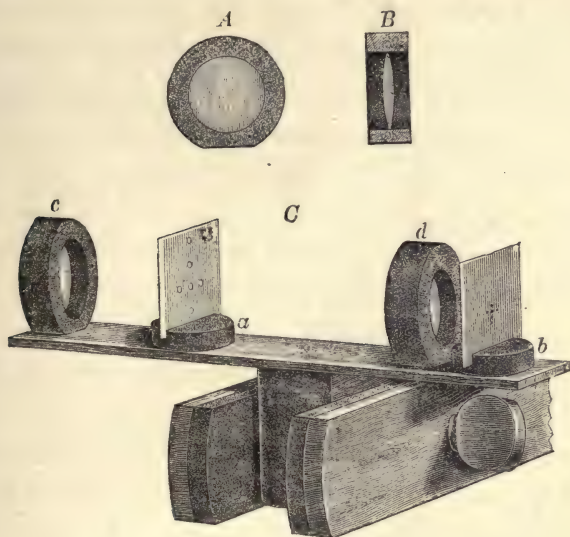


FIG. 285 ($\frac{1}{2}$ real size, *C an. proj.*).

investigations, such as are undertaken by the botanist, physiologist, &c.

The principle of the microscope may be fully demonstrated by means of two lenses, of 3 and 5^{cm} focal length. Get a cork which is about 3^{cm} thick; cut two round discs, each 1^{cm} in thickness; bore holes in the middle of each and widen them with the rat tail, so that the lenses will go into the aperture when moderate pressure is applied. Before the lenses are inserted, a small portion of the edge of each cork ring is filed away, so as to produce a flat surface; care should also be taken not to place the lenses in an oblique position into the frames. In fig. 285 *A* is a front view of the larger lens with the ring, *B* is a section of the same. Both rings with the lenses are then glued upon a small board, 15^{cm} long and 3^{cm} broad; the lens of 5^{cm} focal length, the eye-piece, at one end, and the other lens, the object-glass, at the opposite end, leaving a space of 11^{cm} between them. A common cork is glued to the under side of the board, so that the whole may be clamped in the fork of the retort-stand, as shown in fig. 285 *C*. Two cork discs, *a* and *b*, have an incision made across one of their flat sides: into one of these a piece of stiff writing paper may be stuck, and into the other a piece of sheet

brass. The paper is slightly oiled, so as to render it translucent, and in the brass plate six small holes are made, so as to form a cross $\cdot\cdot\cdot$. The holes are not punched right through, but the brass plate is laid on a piece of lead; the punch receives only a slight blow with the hammer so as to produce a depression, and the file is then applied to the elevations on the opposite side of the brass plate until the metal is filed quite thin, and a hole may be made through the brass by pushing a middle-sized needle through it. The brass plate must be pressed into the incision just sufficiently to bring the cross into a line with the middle of the lenses, when the cork b , which carries the plate, is placed upon the board in the manner shown in the figure. Before the brass plate is put in position, the cork a with the oiled paper is placed about 4^{cm} from the lens c , and looking at it through the lens the cork is moved to and fro until the paper is seen as sharply defined as possible. A flame is then placed at the other end of the board, exactly in a line with the middle of both lenses; and finally the cork with the brass plate set upon the board, about $17^{\text{mm}}\cdot 5$ from the lens d , and moved to and fro until a distinct inverted image of the cross appears upon the oiled paper. With the distances assumed the image on the paper is magnified about four times; the lens c magnifies this image five times, and hence the image seen through c appears $4 \times 5 = 20$ times larger than the object. The paper screen serves for showing that a real image is produced by the object lens, denoted by $a_1 b_1$ in fig. 284. If the paper is removed, the magnified image of the cross is seen still better defined by the eye looking through c . This final image, $a_2 b_2$ in fig. 284, is virtual, and can therefore not be shown on a screen like the real image formed by the object lens.

The experiment must be made in a darkened room, otherwise the real image on the oiled paper will not be distinctly seen. The lenses of a common microscope are usually fixed in their tubes, which are blackened inside. All light which does not proceed from the object itself is thus shut off. In our arrangement the tube is left out in order to exhibit the formation of the image on the paper. If the latter is removed, we may see images of objects which do not even emit as much light as the cross. Thus by holding a piece of fabric in the place of the cross, we may see the threads pretty strongly magnified. A magnifying power of 20 is, however, very small for a microscope. The magnifying power is increased by using object lenses of much shorter focal length, and good microscopes have generally a number of object glasses which may be screwed into the end of the tube, and by which the magnifying power may be made to vary between 30 and 500 times and even more.

Of telescopes there are three principal kinds:—the ‘astronomical,’ the ‘terrestrial,’ and the ‘Galilean.’

The *astronomical telescope* resembles the microscope in this, that the object glass produces a real inverted image of the object, which is magnified by the eye-piece. The image formed by the object glass is, however, not already magnified, as is the case in the microscope, but is smaller than the object, because the distance of the object from the lens is much larger than twice the focal length of the object glass. This focal length is therefore made as large as possible, lest the image produced by it should be too small; and since distant objects cannot be artificially illuminated, the object glass must have a large aperture so as to collect as many rays as possible from the objects to be seen, and thus to render the images of them formed by the telescopes as bright as possible. Thus the large telescopes in astronomical observatories, usually called ‘refractors,’ have object glasses of from 15 to 30 and even 40^{cm} diameter, and from 2 to 7^m focal length.

Fig. 286 shows the principle of the astronomical telescope; ab is the object, a_1b_1 the real image produced

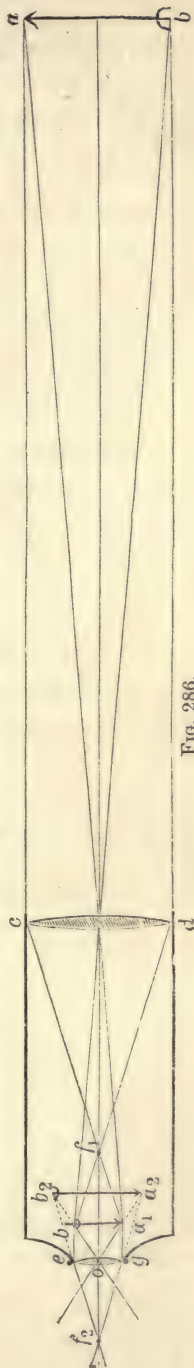


Fig. 286.

by the object glass $c d$; $a_2 b_2$ the virtual image seen by the eye looking through the eye-piece $e g$; f_1 is the focus of the object lens, f_2 the focus of the eye-lens. In the figure the distance of the object from the telescope has been taken very small, otherwise the instrument would have to be drawn on too small a scale. It will be at once seen from the figure that the image $a_2 b_2$ is in reality smaller than the object, but nevertheless it appears to an eye at o larger, because it is much nearer. The image $a_1 b_1$ becomes the larger the farther it is from the lens $c d$ —in other words, the greater the focal length of the object glass. The lens $e g$ magnifies the more the smaller its focal length (compare page 519). The magnifying power of an astronomical telescope is accordingly the greater the greater the focal length of the object glass and the smaller the focal length of the eye-piece. In the astronomical telescope an inverted image of the object is seen. This matters little in the obser-

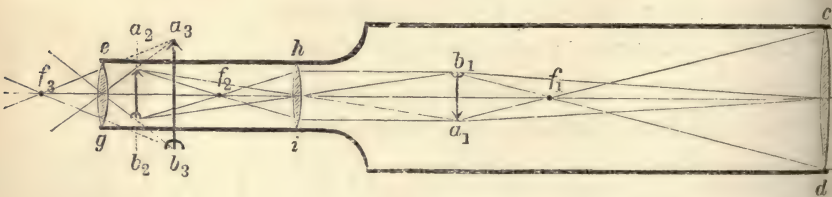


FIG. 287.

vation of celestial bodies, but would be a great inconvenience in the use of the telescope for viewing distant terrestrial objects.

The *terrestrial telescope* consequently differs from the astronomical in producing images in the same position as the objects. The object glass $c d$ (fig. 287) of the terrestrial telescope produces, as in the astronomical, an

inverted image $a_1 b_1$ of the object (left out of the figure to save space). This image is again inverted by the lens hi , which therefore produces an erect image $a_2 b_2$, which is finally viewed through the eye-piece eg , which acts as magnifier and gives the erect image $a_3 b_3$. The foci of the lenses cd , hi , and eg are f_1 , f_2 , and f_3 respectively.

The *Galilean telescope* gives at once an erect image, without the interposition of a third lens. Opera glasses are constructed on this plan. The object glass cd (fig. 288) resembles that of the astronomical and terrestrial telescopes, and produces an image $a_1 b_1$ of the object ab . The position of this image is found, as in all previous cases, by drawing, from one extremity a of the object two rays, ahf_1a_1 and $ai a_1$, of which the former is parallel to the axis and passes through the focus, while the other passes through the centre of the lens. Besides these two rays two additional rays are drawn, viz. aca_1 and aka_1 ; and to avoid confusion the rays which produce the image of b are left out from the figure; the image b_1 can clearly be found easily by drawing rays in the same way as is done for the point a .

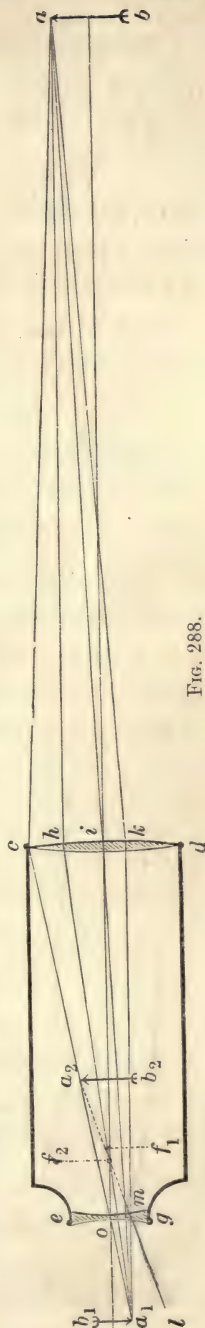


FIG. 288.

The formation of the image $a_1 b_1$ is, however, prevented by the interposition of a *concave* eye-piece eg , which has a small focal length and causes a divergence of the rays from their original direction. The real, inverted image $a_1 b_1$ is converted by the eye-piece into an erect virtual image $a_2 b_2$, which to the eye at o appears considerably larger than the object $a b$. The formation of the image $a_2 b_2$ will be understood if we consider in the first instance that rays from a are falling upon the entire surface of the lens cd , and that all of them are so refracted that they produce an image of a at a_1 . Among these rays there will obviously be one which passes through the centre of the eye-piece, and whose direction is therefore not changed. Let, in our figure, $ca_2 a_1$ be that ray. Similarly there will be one ray, km in the figure, which reaches the eye-piece parallel to the axis. But we know that rays parallel to the axis of a concave lens proceed after refraction as if they originated in the focus; and since f_2 is the focus of the eye-piece eg , the ray km will not proceed towards a_1 , but towards l , as if really coming from f_2 . It follows that the rays ca_1 and km , which, in the absence of the eye-piece, would produce the image a_1 , are diverging after having passed the concave eye-piece in the directions towards a_1 and l , and the eye at o receives the same impression as if these rays proceeded from a_2 , that is, the eye sees at a_2 a virtual image of a . The rays ha_1 and ia_1 are of course also refracted as if they proceeded from a_2 , but their directions after passing the eye-piece are not represented in the figure, for the sake of clearness.

The lenses of telescopes are usually fixed in tubes, which are blackened inside; this ensures steadiness

in the position of the lenses and exclusion of all light which does not proceed from the observed objects. In figures 286 to 288 the walls of the tubes are indicated by somewhat thicker lines. The real form of the tube of a telescope is however very different, and must admit of altering the distance between the object glass and the eye-piece. For since the real image produced by the object glass is the farther from the lens the nearer the object, and since the eye-piece must always have

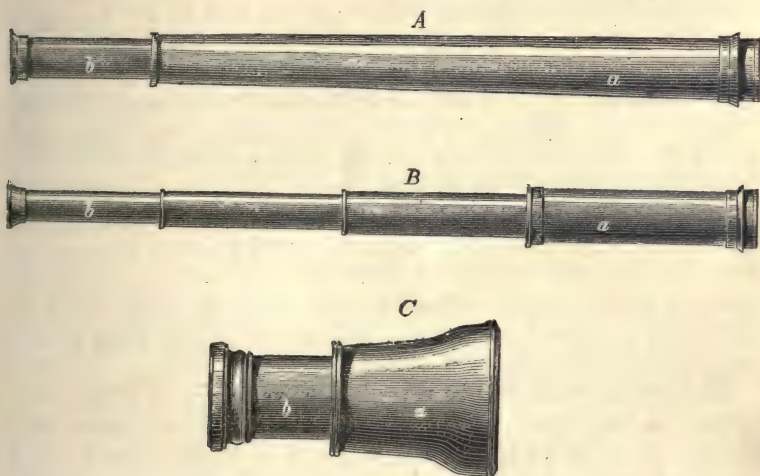


FIG. 289 (*A, B, $\frac{1}{2}$ real size; C, $\frac{1}{2}$ real size*).

the same position with reference to this image, whether it is actually formed, as in the astronomical and terrestrial telescope, or not formed at all, as in the Galilean, it follows that the tube of the telescope must be capable of being lengthened for near objects and shortened for more distant objects. The object glass and the eye-piece are therefore each in separate tubes, which slide one in the other with moderate friction. Fig. 289 shows the external appearance of three kinds of tele-

scopes. *A* is the form of the astronomical (on a small scale), *B* of the terrestrial, and *C* of the Galilean telescope. In all of them *b* denotes the tube which carries the eye-piece, *a* that which carries the object glass. The terrestrial telescope has usually more than the two necessary tubes; it may thus be considerably shortened and more conveniently carried about.

A telescope, like a microscope, can only be constructed by skilled hands. For our purpose, which is the demonstration of the principles on which the instrument acts, a concave lens of 2^{cm} diameter and 5^{cm} focal length will be required, besides the three convex lenses of 28, 5, and 3^{cm} focal length previously used. The three small lenses are provided with cork frames, 3^{cm} in diameter, as for the microscope; the larger lens is fixed in a tube of cardboard, from 6 to 10^{cm} long, and kept in position by means of two rings of cardboard, as explained in the construction of the camera obscura (see page 478). Right and left below this tube pieces of cork are glued upon it, suitably cut and filed so as to ensure a stable position for the tube when placed on the board. The form of these pieces is seen in fig. 290 at *k k*. The two small boards required, *B* and *b*, should be procured from a joiner, each 6^{cm} wide and 1^{cm}·5 thick; one 10^{cm} and the other 50^{cm} long.

The experiment should be made in the evening or in a darkened room. A long table will be required, or two tables will have to be joined, in order to obtain the requisite distances. Three small pieces of candle are arranged near the end of the table, as in fig. 290 *D*, one of them being placed behind the two others and raised above them by means of a piece of cork about 3^{cm} high. The board *B* (fig. 290 *A*, *B*, *C*) is placed upon the table, at a distance of 3^m from the pieces of candle, and directed towards them. The smaller board *b* carries the eye-piece, the frame of which is not glued to the board, but fixed between two pins stuck in the wood. The cardboard tube with the object glass is placed upon the larger board at a suitable distance from the eye-piece. Looking at the candles through the eye-piece, the board *b* is moved to and fro until distinct magnified images of the candles are seen. Care should be taken in moving *b* that its edges are always in the same plane as those of *B*, otherwise the axes of the lenses will not be in a straight line.

For the astronomical telescope, *A* in fig. 290, the convex lens of

5^{cm} focal length is used as the eye-piece *o*, and the tube with the object glass is moved until the distance of the lens from the end of the board *B* is about 15^{cm}.

For the terrestrial telescope the same lens forms the eye-piece, and the convex lens of 3^{cm} focal length serves for the lens *u* required for inverting the primary image. The cork frames for these two lenses

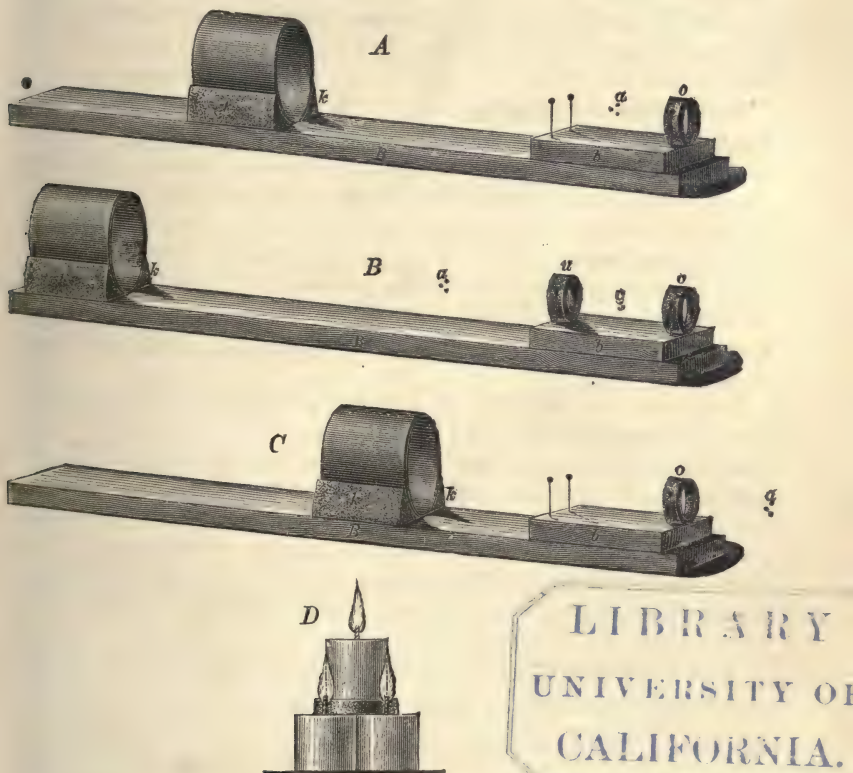


FIG. 290 (*A, B, C*, an. proj., $\frac{1}{5}$ real size; *D*, $\frac{1}{3}$ real size).

are fixed 9^{cm} from one another at the opposite ends of *b*, and the object glass will have to be moved to near the end of *B*.

For the Galilean telescope *C*, the concave lens of 5^{cm} focal length is used as the eye-piece, and the object lens will have to be placed at about the middle of *B*.

The inverted real image produced by the object glass of the astronomical telescope is at *a* in fig. *A*, where the three flames, on account of the small size of the figure, are indicated by dots. The

existence of this image may be demonstrated by means of a piece of oiled paper, as in the case of the microscope. Looking from the side at the paper, the image which appears magnified when seen through the eye-glass o will be seen in its real size. In the case of the telescope the lenses are first adjusted until the candles are distinctly seen; the paper is then placed between the lenses and moved to and fro until the real image appears sharply defined. That the final image formed by the telescope appears larger than the object when seen direct, may easily be proved by looking with the right eye through the eye-piece o and with the left eye direct at the candles.

In the terrestrial telescope, fig. B , a is again the place of the real image produced by the object glass, while the second image, formed by the action of the lens u , is at c . This secondary image is, with the distances assumed here, half the size of a primary one. A paper screen for receiving these images may be placed at a , and afterwards at c . If the experiment is made in the evening, there being no other light except the three candles, and screens of fine tissue paper be used, both images may even be shown at the same time. The screen for a is then placed and adjusted first, and afterwards the screen for c .

In the Galilean telescope it may easily be shown that no real image is formed, by moving a sheet of paper first from the object glass to the eye-piece o , then holding it on the other side of o and moving it slowly farther and farther from the eye-piece; in any position only a patch of light with undefined outlines will be seen on the paper. In fig. C , a denotes the position of the image which would be formed without the interposition of the eye-piece; it can obviously only be received on a screen when the lens o is removed.

For many astronomical purposes telescopes are used in which the object lens is replaced by a concave mirror. Such instruments are called *reflectors*, or 'reflecting telescopes,' and there are various kinds of reflectors in use. Fig. 291 explains the construction of the 'Newtonian reflector.' The end hi of the tube is quite open and directed towards the object to be observed; at the opposite closed end of the tube is the concave mirror cd . This mirror would produce a small inverted image of the object at $a_1 b_1$; but the small inclined mirror reflects the rays forming this image into

a direction at right angles to the axis of the telescope, so as to form the image $a_2 b_2$ near the tube of the instrument. At this place a smaller tube is attached, which carries the eye-piece $e g$. This lens forms for an eye at

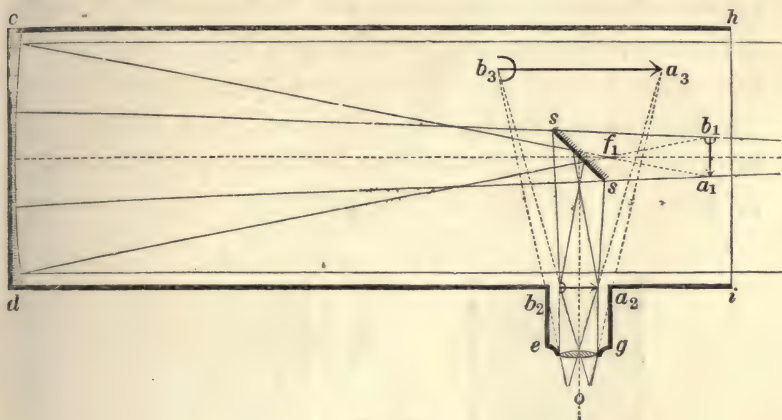


FIG. 291.

o a virtual magnified image $a_3 b_3$, and acts therefore precisely like the eye-piece of the common astronomical telescope.

43. *Binocular vision.*—*The Stereoscope.*—*Various visual effects.*—The same object presents to the eye different aspects when we view it from different points. Thus a six-sided column (fig. 292) appears to an observer on the left like the figure A ; to an observer on the right like B . To the former the left face of the column appears broader than the right face; for the second observer the case is reversed. The same difference in the appearance of objects holds good also for the two eyes of the same person, because the distance between them amounts to several centimetres. If a six-sided pencil is held in a vertical position at a distance of 20 or 25^{cm} from the eyes, and the right and

left eye are alternately shut or covered by the hand, a difference will be discovered in the two aspects of the pencil which corresponds to that between *A* and *B* in fig. 292. When we are looking at an object with both eyes at the same time, we are unconscious of this difference between the two images, but it is precisely the coalescence of these two images into a common one which gives the impression of *solidity*. As long as we use only one eye in looking at bodies they present only length and breadth, like the flat surface of a picture;

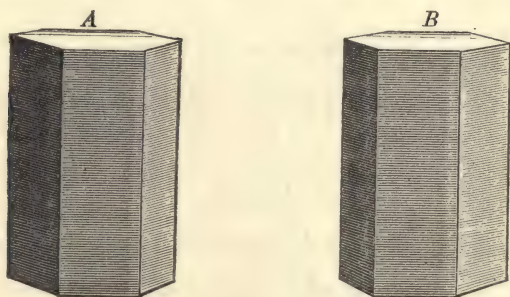


FIG. 292.

but simultaneous vision with both eyes produces the idea of relief, that is, the perception of depth in space. It is true that we scarcely fail to arrive at the same perception when we look at objects with one eye shut, but this is the result of a rapid mental process of which we have become unconscious in consequence of our constant experience of the succession of things in depth. Still our estimation of depth in space is not trustworthy if we rely on the information conveyed by one eye only.

The difficulty of estimating distances with one eye may be shown by the following experiment. Bend one end of a wire, 20^{cm} long and 2 or 3^{mm} thick, into a ring of about 4^{cm} diameter; file the other end to a point, and fasten it into the top of the bar of the retort-stand,

after removing the arm or letting it down as far as possible. Place the stand on a table which stands freely in the middle of the room, take into your hand the lower part of a walking stick which has a crook handle, shut one eye, approach the retort-stand from a distance of several metres, and attempt to put the crook through the ring by stretching out the arm which carries the stick. At almost every trial the crook will either fall short of the ring or be stretched beyond it; but if both eyes are used, the crook is easily put into the ring at once.

The ring should be fixed nearly in a horizontal line with the head of the experimenter, or very little lower. If the ring be suspended by a fine thread from the ceiling, it is still more difficult to put the crook into it. If the ring is suspended in this manner, it must first be allowed to settle in a steady position before the experiment is made.

An accurately drawn picture of an object makes the same impression upon a single eye, at least as regards the external form, as the object itself, for one eye is as little able to estimate directly the relative distances of the various parts of the object as the picture is of giving a direct representation of these distances. As a consequence of this a picture produces the greatest resemblance to reality when viewed with one eye only; as soon as the other eye is opened, the picture presents of course the same aspect to either eye, and the difference between it and the appearance of the real objects is at once detected. Thus after viewing with one eye the picture of a church interior, or of a row of pillars, the depth of the space represented will make the impression of reality. This illusion, however, will at once be destroyed on opening the other eye; the parts of the picture which form the foreground appear to recede; the background seems to move forward, and the whole merges into the flat surface of the picture.

That the impression of solidity is produced by our seeing two different images of the same object when we use both eyes, is strikingly demonstrated by the *stereoscope*. Two pictures, each representing the same object as seen by either eye alone, are by means of the stereoscope presented to the eyes, but in such a manner that each eye sees only one picture, while the apparent positions of the pictures coincide and both pictures are therefore seen in the same place. The solidity of the object is brought out the more strikingly, the greater the correctness of the two pictures which form the combination.

Let the left eye be at A in fig. 293, and the right

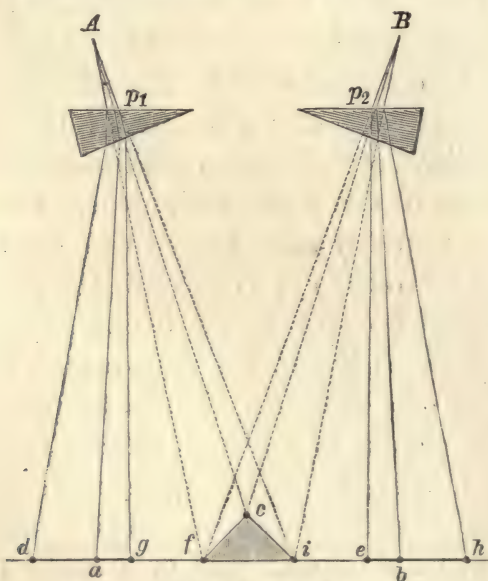


FIG. 293 ($\frac{1}{2}$ real size).

at B ; let a and b be the corresponding pictures for each eye, and p_1 , p_2 , two prisms of glass through which the pictures are seen. A prism, as we have seen, refracts

rays of light so that objects seen through the prism appear to be nearer to the refracting edge; the prism p_1 therefore refracts the ray ap_1 in the direction p_1A , as if it proceeded from c . The prism p_2 refracts the ray bp_2 so that to the eye at B it also appears to proceed from c . The effect of this is—provided that the two pictures a and b are drawn just as a body at c would appear to the eyes at A and B if the prisms were not there—that the object really appears to be at c . And as the points a and b combine to form the point c , so d and e unite to form the point f , g and h to form the point i .

In most stereoscopes the prisms have not flat but convex

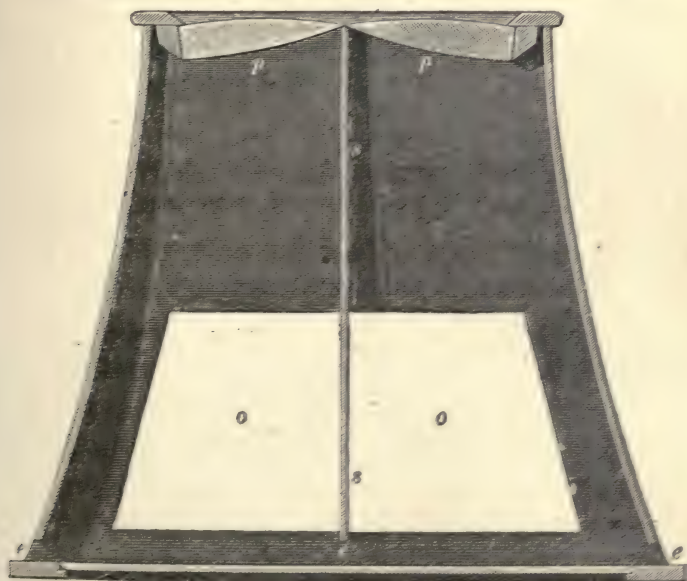


FIG. 294 ($\frac{1}{2}$ real size).

faces, and therefore, in addition to causing the lateral displacement, act like convex lenses, and magnify the

picture. These lenticular prisms are generally set in the top of a four-sided pyramidal box, which is wider at the bottom, where the pictures are placed, than at the top. Fig. 294 shows a vertical section of the box; *pp* are the lenticular prisms, *ss* is a partition within the box which prevents each eye from seeing the picture prepared for the other eye. Light falls into the box through the opening *oo* upon the two pictures, which are usually fastened side by side upon a piece of cardboard; this 'slide' is introduced through the horizontal opening *ee*.

The aperture *oo* is generally closed by a moveable lid. If the pictures are upon opaque paper the lid must be opened, and the stereoscope must be inclined so as to allow the light of the sky or some other light to illuminate the pictures. If the pictures are on transparent paper or glass the lid must be shut, and the instrument held towards the sky or the artificial light, for which purpose the bottom of the instrument is made of ground glass, or has two openings, each of the size of the binocular picture.

It is not always possible to form at once a single image of the two pictures, but when we have succeeded in it, the appearance of relief or solidity is most perfect and surprising. If we do not succeed, the head should be moved a little so as to bring the eyes nearer or farther from the instrument. Since the distance of distinct vision and the distance between the eyes (about 7^{cm}) vary in different persons, the same stereoscope will not be suitable for all eyes, unless some adjustment be attached which permits an alteration in the relative distance between the prisms and the pictures, and also in that between one prism and the other. The absence of such an adjustment in most stereoscopes is the cause of one and the same instrument being well adapted for one person but unsuitable for another.

A convenient form of the instrument may be called 'stereoscopic spectacles.' The two prisms are set into a kind of spectacle-frame, to which a handle is fixed, so that by moving them to or from the pictures, distinct vision is obtained by adapting the distance to the individual distance of vision of the person using them. In consequence of the absence of any partition between the two pictures,

each eye sees both; of these four pictures, two unite to form one, which gives the impression of solidity, while the two others are flat, and so faint as to interfere little if the attention is directed to the central one.

Stereoscopic views of various objects, produced by photography, may now be had in great variety and at moderate prices. The fig. 295 gives two binocular pictures, in which the difference between the right and left picture is very obvious. *A* represents

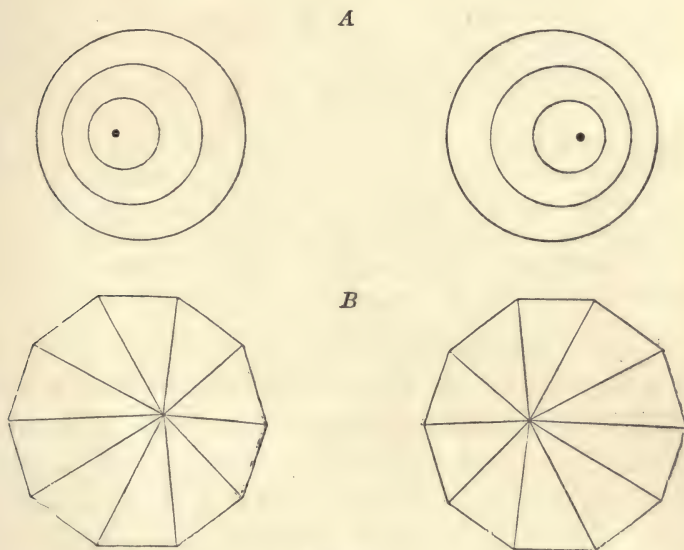


FIG. 295.

three concentric circles behind one another; *B* is a ten-sided pyramid. The two binocular pictures of the six-sided column in fig. 292 would, if viewed by means of a stereoscope, similarly combine to give the appearance of solidity.

Two impressions of printed lines, or of a drawing, which are perfectly alike will appear as a single impression, if they are placed side by side and viewed in the stereoscope like two binocular pictures. But if some portions in one impression are a little more to the left, while the corresponding portions in the other impression stand more to the right, these portions will appear either higher or lower than the rest. Thus in the following two impressions, when looked at by the stereoscope, the 1st, 3rd, and 5th lines appear depressed, while the 2nd, 4th, and 6th lines appear raised.

V

Those lines which in the print on the left side are farther to the right than in that on the right, appear in the stereoscope raised up above the rest.

Those lines which in the print on the left side are farther to the right than in that on the right, appear in the stereoscope raised up above the rest.

Λ

Since even the most perfect imitation of a print or drawing differs in some points from the original, the stereoscope is a means of detecting such differences; for if the original—for example, a banknote—be compared with the counterfeit, those letters which are not exactly in the same position in both would appear raised or lowered when viewed in the stereoscope.

The sensation produced by visible objects continues for a very short time after the actual impression from which it results has ceased, as when a body is in rapid motion or is suddenly hidden behind other objects. During the twinkling of the eye, that is the rapid closing of the eyelids for the purpose of diffusing a lubricating fluid over the cornea, we never lose sight of the objects we are viewing. In like manner, when we whirl a glowing splinter of wood with a rapid motion, its glowing end will produce a complete circle of light; if the motion is slower, a luminous arc of a circle will be seen; but in each case it is obvious that the luminous extremity can only be in one point of the circle at the same instant.

All such cases depend on the *duration of impressions of light* on the retina; and the brighter the visible body is, compared with the surrounding objects, the more

easy it is to observe the effects resulting from this duration of impressions. If a circular piece of cardboard, of which the four quarters are alternately covered by black and white paper, as in fig. 296, is fixed on the whirling-table and rapidly turned, the disc will appear uniformly grey. The reason of this is that we never really lose the impression of the white, nor that of the black. The impressions of white and black continue together; hence the disc appears grey, which is nothing else but a mixture of white and black.



If instead of a disc containing only white and black, one containing the seven principal colours of the spectrum, as fig. III. on the frontispiece, is fixed to the whirling table, it will also appear grey if rapidly turned. Since white light may be revolved into coloured light, coloured light should be capable of being compounded so as to produce again white light; and apparatus of various kinds are constructed, by means of which the colours of the spectrum may be again reunited into a pure white light. A disc coloured similarly to that in fig. III. is called a 'Newton's disc,' because Sir Isaac Newton demonstrated by it the recombination of decomposed light. But for two reasons our disc does not reproduce *white* light when turned rapidly. In the first place, consider one of the coloured sectors—for example, the red one. If this strip is to appear white, it must give out at the same time the light of the other colours, viz., orange, yellow, green, &c.; in other words, the quantity of light given out by the

seven strips together must be given out by the red alone if it is to appear white, and as the spectrum in our disc is given twice, it follows that the quantity of light emitted by the whole fourteen strips would have to be emitted by two, in order to make the disc appear white. Thus, although the colours are actually by the duration of the impression recomposed to white, there remains still a deficiency of light, which renders the disc by far less bright than a really white disc upon which the same amount of light falls. If more light is thrown upon the rotating disc than upon the surrounding objects, the disc becomes really nearly white. In the second place we must consider that it is impossible to obtain colours—that is, pigments—which are as pure as the colours of the spectrum, each pigment being, in fact, a combination of various colours; nor can the coloured sectors be arranged in the exact proportions side by side in which they appear in the spectrum.

A separate impression of fig. III. is added to the frontispiece; it will enable the student to experiment with it, after cutting it away and making a hole in the middle. The black edge should not be removed, as the grey, by contrast with the black, appears more nearly white than without the black edge. Additional light may be thrown upon the coloured disc in the following manner:—Place the whirling-table vertically upon a table near a window, and a retort-stand upon the window-sill. Clamp a small mirror in the fork of the retort-stand, and move it until it reflects direct sunlight upon the coloured disc. Only a portion of the disc, in the form of a parallelogram, will be thus more bright than the vicinity, but the effect will be obvious at once.

If a prism be applied to the examination of each of the seven colours in the disc, each may be proved to be not a simple colour, but a mixture of various colours. In order to avoid in this experiment that any one of



LIBRARY
UNIVERSITY
CALIFORNIA

the colours under examination should be rendered indistinct by the interference of the images of the various objects around, which by the refractive effects of the prism may possibly be superposed upon the colours, each colour should be surrounded by a dark space. A slit, 25 or 30^{mm} long and 3 or 4^{mm} broad, is cut in the middle of a square piece of thin cardboard of quarto size; the cardboard and especially the inner edges of the slit are painted black by a mixture of lampblack and a little glue. When the paint is dry, any single colour of the disc is applied close to the slit, and whilst holding both together in the left hand, the arm is stretched out, and the colour viewed through the sulphide of carbon prism, care being taken to turn the back to the window in order to have as much light as possible thrown upon the slit—not direct sunlight, but diffused daylight. The image of the slit will, of course, have to be looked for towards the left, if the refracting edge of the prism is on the left side of the observer. This edge as well as the slit must be vertical.

Each colour will be shown by the prism to be more or less compounded of others. If the Blue is behind the slit it gives out a spectrum in which only the Yellow is wanting. The Red contains, besides Red and a little Orange, some traces of Green and Violet; the Green contains only the portion of the spectrum between Yellowish-green and Bluish-green, besides a faint Red. Hence the Red and Green are comparatively more simple than the other colours.

If, instead of the colours of the disc, other coloured bodies be placed behind the slit and examined by the

prism, their colours will always be found to be compounds, that is, a sum of various colours. It follows from this that if one colour represents a compound of simple colours which forms one part of the complete spectrum, while another colour is a compound containing the remaining part of the spectrum, these two colours will together produce white light. It is therefore not requisite to blend all colours in order to produce White. Certain mixtures of only two colours will give white light, and any pairs of colours which combined produce white light are called *complementary colours*. To find the colour complementary to any given colour is not always easy, but it is more easy to find the complementary colour for any of those represented in our Newton's disc. Let a piece of thin blackened cardboard be cut of such a shape that, when placed upon the coloured disc, two equally coloured opposite sectors, and also the small black circle in the middle, may be covered by it. Let a hole be made in its centre, and the cardboard be screwed, with the disc beneath it, upon the whirling-table. The visible remainder of the disc when turned no longer appears white, but coloured in the following manner:—When the yellow is covered, the remainder appears violet; when the green is covered, the remainder appears bluish-red; when the blue is covered, the remainder appears orange. The colours which thus appear successively during the experiment, that is, Violet, Bluish-red, Orange, are hence proved to be complementary to Yellow, Green, and Blue respectively, because we know that White would be produced if in each case the whole of the disc had been uncovered.

If a strong impression is created by some definite colour, the eye perceives the complementary colour, although it has no real existence. Thus, let a burning candle be placed at a small distance from a white sheet of paper, and near a window, so that two nearly equally dark shadows of a pencil may be thrown upon the paper, due respectively to the light of the window and to that of the candle. The shadows will not appear both grey, but one will have a bluish, the other a reddish tinge. The reason is, that the light of the candle is not white, but yellowish, and that therefore the sheet of paper upon which the light of the candle and diffused daylight fall reflects a yellowish light. That portion of the paper, however, upon which the shadow caused by the candle is projected receives none of the yellowish light, and by contrast with the adjoining large yellow space it appears bluish. On the other hand, the shadow caused by the daylight receives the yellowish light of the candle, hence by contrast with the much less yellow adjoining space, and with the bluish shadow caused by the candle, it appears reddish. If a small piece of grey paper is placed upon a surface which is of a bright colour, for example, on a piece of coloured fabric or (unglazed) paper, and both are looked at while exposed to the direct rays of the sun, or strongly illuminated by some other means, the grey paper will exhibit the complementary colour of that of the surface below it; if the latter is blue, the paper appears yellow; if red, the grey paper appears green, and so on. The name of 'accidental colours' has been given to those colours which are perceived in such cases without their having an actual existence.

The persistence of impressions of light on the retina may be used to make an object of which a series of figures is drawn on cardboard appear as if it were in motion. Look first at *A* in fig. 297, then for a very short time at *B*, then at *C*, and so on along the whole series. The eye will very nearly receive the impression of a moving pendulum ; for it sees successively twelve figures, each of which is very little different from the

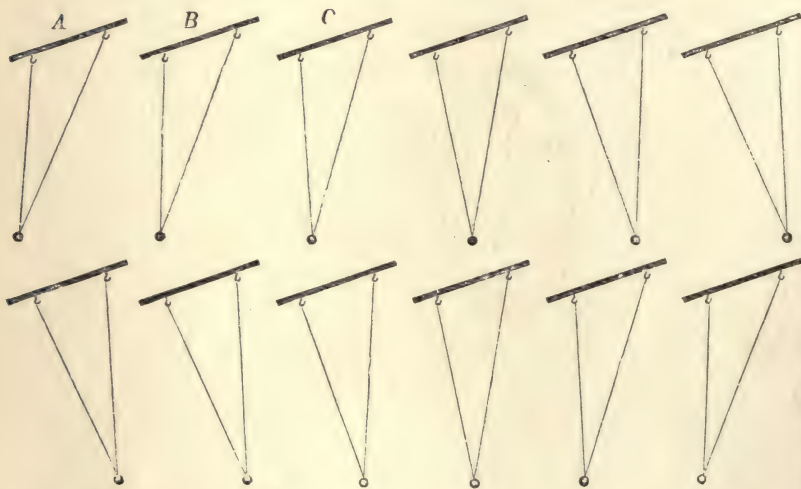


FIG. 297.

next, so that the sudden transition from one to another is not felt, but an impression is produced as if one and the same object were gradually changing. By presenting the figures successively to the eye, as for instance by drawing a strip of paper with the figures on it before the eye, the impression of motion is very imperfect ; care must be taken that each figure is seen only in a definite place, and that its onward motion is not perceived at all. This may be accomplished by

the so-called 'magic disc' or 'Phenakistokope,' fig. 298. It consists of a circular disc having as many apertures, at equal distances from one another, near the edge of the disc, as there are figures of the object. The figures are placed in a narrower circle, so that each is opposite to an aperture. This disc is connected by the middle to a handle round which it can be made to revolve rapidly. The handle is held in the left hand, the side

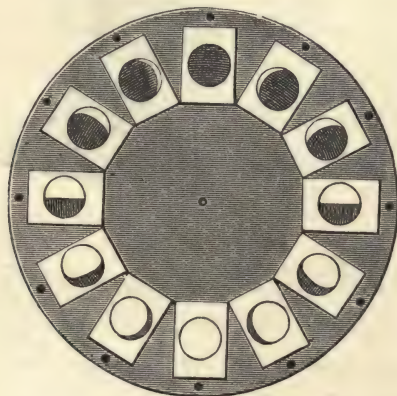


FIG. 298 ($\frac{1}{10}$ real size).

with the figures presented to a mirror, and the eye applied to one of the holes. When the disc is turned by applying the right hand to the edge, the successive holes pass the eye very rapidly, and, as each hole is passing the eye, the figure below it becomes visible for an instant in the mirror, and this image persists until the next makes its appearance, into which it gradually merges, so that all together produce the impression of one and the same object.

The same effect is produced by the 'zoetrope' or 'wheel of life,' fig. 299. This is a kind of drum made

of cardboard, open at the top, and covered outside with dark paper. Its width is about 27^{cm}, its height 20^{cm}; at equal distances from one another there are in the side of the drum twelve vertical slits, 6^{mm} wide, which

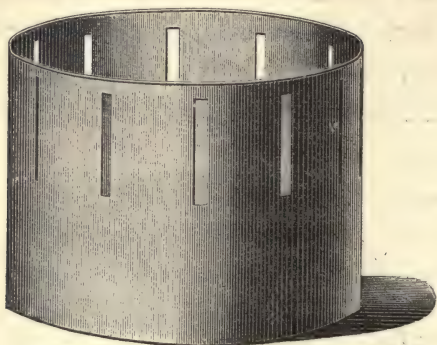


FIG. 299 ($\frac{1}{8}$ real size).

reach from the middle to near the upper edge. A strip of paper with twelve figures is placed inside, so as to be everywhere close to the wall, and the drum is then made to rotate while the eye is applied to any of the slits, looking down at the figures inside.

The 'wheel of life' and various strips of figures may easily be purchased at a toy-dealer's. The motion of the wheel is, however, much better than that of those purchased in shops if it is specially ordered and made so that it can be fixed to the whirling-table. The sets of figures sold for the 'wheel of life' may be used for constructing a magic disc. Upon a disc of cardboard 23^{cm}·5 in diameter, draw a circle with a radius of 13^{cm}·6. Divide this circle into twelve equal parts (see page 353), and join the points of division by straight lines, forming a regular polygon of twelve sides. Cut the twelve figures out of the strip for the 'wheel of life,' taking care to do it accurately, so that the separate pieces, may be rectangular and equal to one another, and paste them in their proper succession upon the disc, so that the lower edge of each is exactly in a line with a side of the polygon. Several such discs may be made, and

figures pasted upon both sides. A larger disc, of 25^{cm} diameter, is provided with twelve apertures at equal distances from one another close to the edge, and each 1^{cm} wide. Both discs are perforated in the middle by a hole 6^{mm} wide, and placed together upon the disc of the whirling-table, from which the cord has been removed, the larger disc with the holes being nearest to the disc of the whirling-table. The frame of the whirling-table is now, with the help of the left hand and the left arm, placed upright before a mirror which is fixed to a wall, the eye is applied to one of the holes, and the disc turned with the right hand.

The eye, as has been seen in the case of accidental colours, is liable to a class of deceptions which are usually called *optical delusions*. The combination of lines represented in fig. 300 is an illustration of such a

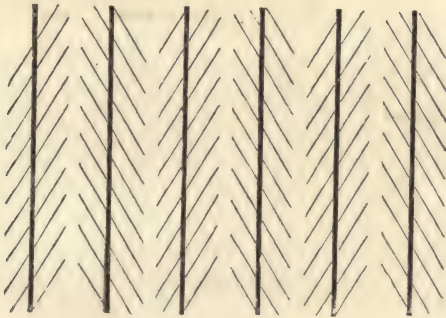


FIG. 300.

delusion. The thick black lines are throughout parallel, that is, at equal distances from one another, as may easily be ascertained by means of a pair of compasses. Nevertheless, they appear to approach one another at the top and bottom alternately. The delusion is caused by the presence of the thin cross-lines, as may be seen by holding the page horizontally in a line with the eye, and looking along it. In this posi-

tion the thin lines are scarcely perceived, and the thick lines are seen to be all parallel to one another. On the other hand, the delusion becomes still greater when the book is held before the eye in a perpendicular position, and is then somewhat inclined either to the right or to the left.

ELECTRICITY AND MAGNETISM.

A. *Frictional Electricity.*

44. *Electrical attraction and repulsion. Conductors and Non-conductors.*—A small cork ball, from 6 to 10^{mm} diameter, is attached to a linen or cotton thread, between 20 and 40^{cm} long, and suspended from the retort stand or the wooden frame shown in fig. 35, or a suitably bent wire frame, as in fig. 301. When a stick of sealing-wax previously rubbed with a piece of flannel is held near to the cork ball, the ball will be attracted by the sealing-wax, and even adhere to it for a short time. Ebonite, sulphur, and many other bodies, when rubbed with a piece of woollen cloth, manifest the same behaviour. A piece of writing-paper, well dried before a fire, and brushed over a few times with a dry, warm cloth-brush, attracts the cork ball strongly when brought near to it. Glass will exhibit the same attraction, but it must be rubbed either with silk or an *amalgam*, that is, an alloy of mercury and other metals spread over a piece of wool or leather.

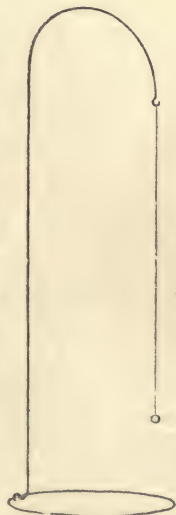


FIG. 301. (*an. proj.*
 $\frac{1}{8}$ real size.)

These bodies manifest thus, when rubbed, an attractive

force which they do not exhibit under ordinary circumstances. This attractive force was first discovered in rubbed amber, and from the Greek word for amber (*ἤλεκτρον*, *electron*), bodies which manifest this attraction have been called 'electric,' while the cause of the attraction, and of other phenomena related to it, has been termed 'Electricity.' As long as bodies are in their usual state they are said to be 'neutral' or 'non-electric;' to render them electric, we must 'electrify' them by operations which have been partly already alluded to or will be described hereafter, and the bodies are then often called 'electrified' or 'electrically excited.'

Substances used for electrical experiments must be perfectly dry. Sealing-wax, ebonite, and glass may be dried by gently heating them over a lamp; sulphur is apt to break to pieces if not heated very cautiously. The pieces of flannel or silk used for rubbing must also be dried thoroughly by holding them for a short time before a fire, without scorching them, or, in the summer, by placing them in the sun. A stick of glass, about 1^{cm} thick, and 40 or 50^{cm} long, is much used for electrical experiments. Some kinds of glass, however, are apt to condense the vapour of the atmosphere on the surface, so that an invisible layer of moisture is formed; such glass rods will, even after being heated, refuse to show signs of electricity. The student should therefore endeavour to procure from the dealers at least two glass rods which will become at once electrified when rubbed, provided they are not *visibly* moist, in which case they need only be wiped with a cloth to render them again available for the experiments.

Amalgam for electrical experiments consists mostly of a mixture of mercury, zinc, and tin, mixed in proportions which are variously stated by different writers. Its preparation should not be attempted by an unpractised hand; the student should rather buy a small quantity ready made, and if it is not to be had, he should scrape the silvering off a piece of old looking-glass, although this consists of mercury and tin only. A useful amalgam is obtained by rubbing 15 grammes of mercury with an equal weight of crumpled tinfoil in a china or stone mortar, until a crumbly mass is obtained. A piece of flannel or leather, upon the surface of which powdered amalgam

has been well rubbed, electrifies far more readily than a piece of silk. The amalgam is poisonous, and acts like mercury on gold and silver.

The piece of cloth upon which the amalgam has been spread should be laid upon the palm of the left hand and on it the glass rod which is held in the right hand. The left hand is then closed, so that the cloth may completely embrace the glass rod, which, by moving the right hand, is repeatedly drawn to and fro. Finally the left hand is opened when the right hand is nearest to it.

The cork ball is first cut into shape with a sharp knife (a razor is the best for the purpose, but it soon becomes blunt if the cork is not quite sound and very soft), and then filed so as to be nearly round; it need not be exactly globular, but must have no edges or projecting points. The thread from which it is suspended is obtained by untwisting common sewing thread, and using one of the several filaments of which the whole consists; such a filament is more flexible than a twisted thread. One end is passed through the cork ball by means of a fine needle and secured by a knot at the other end. The thread should be cut close to the knot and pulled so that the knot disappears in the cork.

Balls made of the pith of the elder tree are still better for these experiments, and may be purchased at the dealers in electrical apparatus.

A small moveable ball suspended in the manner just described is called an *electrical pendulum*.

Even heavier bodies than pith or cork balls and small pieces of paper may be set in motion by electrical attraction if they are suspended so as to move easily. Two corks of about the same size are fixed to the ends of a wire, 40^{cm} long and 2^{mm} thick, bent as in fig. 302 A, and suspended in the middle by a very thin thread. If an electrified glass rod is brought near to one of the corks, the latter is attracted, and if the glass rod is continually moved in a circle away from the approaching cork the wire with the corks will revolve round the thread as axis.

The electrified body itself, if freely suspended, may be set in motion by the attraction between it and an un-

electrified body. Fig. 302 *B* shows the mode of suspending the glass rod. The hand may be simply brought near to one end of the excited glass rod, and the latter will follow the hand as the cork in the previous experiment, and may similarly be made to revolve. A long

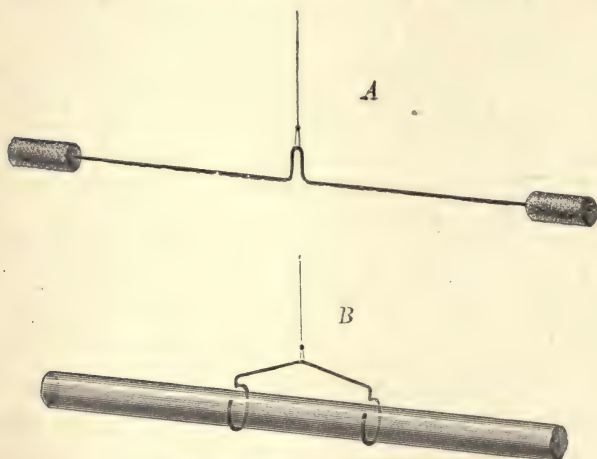


FIG. 302 (*an. proj.* ; $A \frac{1}{5}$, $B \frac{1}{3}$ real size).

stick of sealing-wax, made by fixing together two sticks at the ends, when rubbed with flannel and similarly suspended, may be set in rotatory motion by the hand or any other non-electric body, for example, a piece of wood, a metal spoon, a hammer, &c.

For rotatory motion these bodies are best suspended by a thread of untwisted silk or a horse hair; with a common twisted thread it takes too much time before a suspended body comes to rest. A twisted thread may, however, be used by first holding the rod by the middle after placing it in the bent wire, and then releasing it; as soon as the direction in which the thread turns the rod is seen, the electrified body is quickly brought near the bar on the side opposite to that in which it is moved by the thread, and it will now be moved in a contrary direction by the electrical attraction. Without this precaution the motion produced by electrical attraction could not be distinguished from the motion produced by the twist of the

thread, while with this precaution it will be seen that the electrical attraction is stronger than the torsion of the thread.

The moveable rod should not be suspended from the support in fig. 85. It will be more accessible from all sides if suspended from a hook or nail fastened in the ceiling of the room, to which first a wire is attached, which reaches to about 1·5 or 2^m from the floor. The end of the wire is bent into a small loop, and to this the suspending thread or hair is tied.

If a rubbed glass rod is freely suspended, and another rubbed glass rod is brought near to it, they repel one another. This happens also if the same experiment is made with two sticks of sealing-wax. Other bodies in the form of bars, similarly experimented on, show the same behaviour: electrified substances of the same kind repel one another. If, on the contrary, an electrified glass rod be brought near to an electrified stick of sealing-wax, one of these two bodies being capable of moving freely, attraction will be manifested; similarly, ebonite and glass will attract one another when electrified. Attraction, however, does not always take place between *different* substances in the electric state: a rubbed stick of sealing-wax is repelled by a rubbed bar of sulphur or one of ebonite.

In experiments on repulsion we must be sure that both bodies are charged pretty strongly; for if one body has a weak charge and the other a strong one, the former body behaves as if it were un-electrical, that is, it is attracted by the other. The bodies should therefore be tested by bringing them near to the electrical pendulum; when strongly charged, they will attract the ball at an appreciable distance.

The hand which holds one of the electrified bodies should be kept as far as possible from the suspended body; otherwise the attraction between the latter and the non-electrical hand may possibly overcome the repulsion between the two bodies.

If all bodies which become electric are thus made to act upon each other it is found that they may be

arranged in two great groups : each body included in either group repels every body in the same group, but attracts every body in the other group. In order to explain this fact and many other electrical phenomena, it is supposed that there are two different electricities, or rather electrical states, which bodies may assume, and that bodies which are in the same state repel one another, while those which are in an opposite state attract one another; or, more briefly, *like electricities repel, opposite electricities attract each other*. One of these electricities is called *positive*, the other *negative* electricity.

Of the substances already mentioned, sealing-wax, sulphur, amber, ebonite, paper, become negatively electrified when rubbed; glass becomes positive. If the excited glass rod is held over the face, a sensation like that produced by cobwebs spread over the face will immediately be felt, and a peculiar smell may often be noticed, not unlike that of phosphorus. The former sensation arises from the attraction exerted by the glass rod upon the small hairs which cover the surface of the skin; the smell is due to the fact that the oxygen of the air assumes a different condition in the vicinity of electrical action; in this condition oxygen is called 'ozone.'

If the knuckle of a bent finger be drawn along the excited rod, at a distance of a few millimetres from it, a slight crackling sound will be heard, a faint prick will be felt, and if the room is dark, a faint flash of light, called the 'electric spark,' may be seen.

Bodies may become electric, not only by friction, but also by touching them with another body which is already electrified. If an excited glass rod is brought within a few centimetres of a few cork or pith balls

placed upon the table, these will first be attracted, but as soon as they touch the rod they are as strongly repelled. They have, by contact with the glass rod, become electric, and as their electricity is the same as that of the rod, they are repelled by it.

The same fact may be shown by the electrical pendulum, provided that the ball is suspended by a thread of silk, not one of cotton or linen—for reasons which will soon become apparent. The suspended ball is first attracted, and after contact repelled, by the glass rod. That the ball is now electric is shown by bringing the hand near to it; it is attracted by the hand. By contact with the hand, however, the ball loses its electricity.

The silk thread must be very fine; a single fibre wound off a cocoon is best for the purpose. If this cannot be obtained, a fibre as fine and long as possible should be carefully drawn out of a thread of untwisted (floss) silk. The length of the pendulum should not be less than 15^{cm}. Such a fine fibre cannot be well prevented by a knot from slipping through the hole made by the needle; it should therefore be attached to the ball with a very small bit of wax which has been softened between the fingers.

The silk thread must be dried, if the experiments are to succeed. Over the lamp the thread is easily scorched; it is best to hold it near a fire, or to wrap it round a wire which has been made as hot as will allow of its still being handled without inconvenience.

A rod of glass or sealing-wax which has been rubbed only at one end becomes electric only at the end at which it has been rubbed; only this end attracts the pendulum on the silk thread, and repels it after contact. Many other bodies which have been electrified by contact behave differently. A pretty long brass wire, about 1^{mm} thick, has one end turned into a small loop, *c* in fig. 303 *A*; a similar loop is made at the other end, and the wire bent downwards; to the extremity a flat disc of

metal, b , 2 or 3^{cm} in diameter, is soldered, and the wire stretched and supported by two stout cords or thin ribbons of silk. The wire should be 1 or 2^m shorter than the length of the room, and the ends of the silk

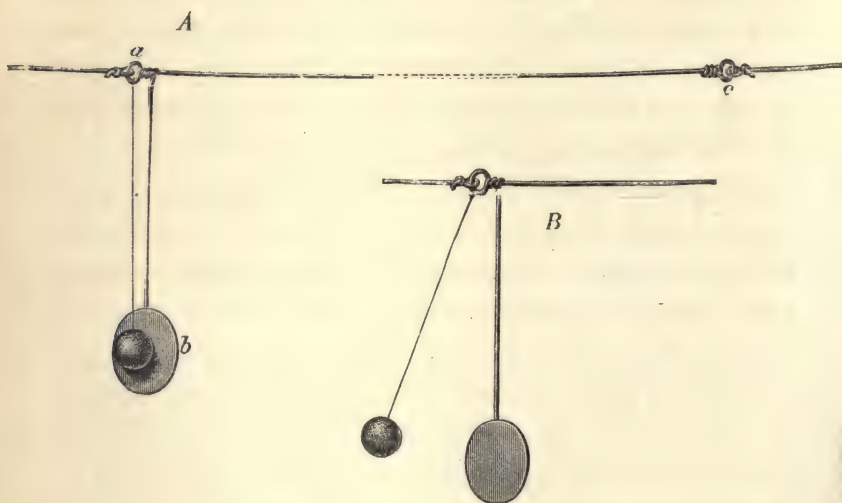


FIG. 303 (*an. proj.*, $\frac{1}{2}$ real size.)

supports tied to nails driven into the wall, or to the hinges of two opposite doors. An electric pendulum is finally suspended at a , in the manner shown in the figure.

When the rubbed glass rod is moved along the edge of the disc, so that the latter may take up a considerable amount of the electricity of the glass, the pendulum will also become electric, and will be repelled, as in fig. 303 B , the electricities being of the same kind, viz., positive. When the disc is now touched by the hand, a small spark passes between disc and hand, the electricity passes away through the body of the experimenter, and the pendulum falls back again into its position of equilibrium. If

any other part of the wire be electrified by the glass rod, for example, by drawing it along *a*, or the middle of the wire, or even along *c*, the pendulum is also repelled. It follows that the disc becomes electric whether the glass rod is brought in direct contact with it or communicates its electricity only indirectly through the wire. Whatever the length of the wire, if electrified at the end *c*, the end *b* also immediately manifests electricity; the electricity thus moves rapidly through the whole length of the wire, and the wire is hence called a *conductor* of electricity. The human body, the floor of a room, the ground, are also conductors; this explains why electricity disappears when we touch an electric body by the hand; the electricity of the wire or the silk pendulum passes through our body into the ground. It follows further that it is as immaterial at what point we touch a conductor in order to remove its electricity as it is immaterial at what point we communicate to it electricity: a conductor becomes electric instantaneously over its whole extent, and loses all its electricity instantaneously. Vegetable fibres, like cotton and linen, are conductors; a cork ball suspended by thread made of these substances can therefore never assume the electrical state, since all electricity communicated to it disappears through the thread. A ball suspended in this manner can only be attracted by an electrical body, but never repelled.

Electricity does not diffuse itself over a thread of silk, or a rod of glass, sealing-wax, sulphur, or ebonite, as it does over a metallic wire. Such substances are hence called *non-conductors* or 'insulators.' In order to see whether a given body is a conductor or insulator, it

is only necessary to bring it in contact with the electrified wire; if the body is a conductor, it withdraws all electricity from the wire, and the pendulum drops; if an insulator, the pendulum is not affected by the contact of wire and body. If a number of bodies are tried in this manner, it will be found that all metals, charcoal, wood, paper, vegetable fibre, are conductors, while all those bodies which may be electrified by rubbing when held in the hand are insulators. When the electrified wire is touched with a splinter of wood or a strip of paper, which have been first rendered perfectly dry by warming them for some time, the pendulum will not drop instantly, but will do so slowly; the reason is, that these bodies are bad conductors and withdraw the electricity from the wire only gradually; they would, in fact, be insulators were it not for their tendency to absorb moisture from the air, and the more moisture they absorb the better they conduct. That water is a conductor is easily shown by moistening a non-conductor, for example a stick of sealing-wax, all over with water; if the electrified wire be now touched with it the pendulum drops immediately. Glass rods which are serviceable for electrical experiments are not easily moistened all over; the water runs into single drops, unconnected with one another, and therefore incapable of conducting electricity: some kinds of glass, again, are conductors as long as the coating of moisture which they condense on their surface is not removed by warming them.

Not all liquids are conductors. Fatty oils, for example, are non-conductors, as may be shown by covering a stick of sealing-wax with oil. In contact

with the electric wire it affects the pendulum as little as the dry stick of sealing-wax.

A conductor can be electrified only when contact between it and other conductors is avoided, so that the escape of its electricity is prevented. The conductor must therefore be supported exclusively by non-conductors, in which case it is said to be *insulated*.

A body may be insulated by suspending it on silk threads or placing it on supports of glass or sealing-wax. Supports of sealing-wax are easily made, but also easily broken; glass supports are rarely good, unless they are coated with shellac; this is a resinous substance, usually brown, but there exists also a bleached sort which is nearly white. A solution of it in spirits of wine is sold as a furniture polish under the name 'shellac-varnish.' This is usually rather opaque; in order to obtain a nice transparent varnish for glass used in electrical experiments, let it stand until the whole has separated into two layers, of which the lower one is light brown, opaque and thick, while the upper layer is dark brown, transparent and thin; carefully pour off the upper layer and use it for varnishing glass; the lower layer may be used for wood. The clear solution must be applied with a camel-hair brush to the *warmed* glass, if the coating is to be bright and transparent; if the glass is cold, the coating is dull, whitish, and turbid. The glass should be warmed over a lamp sufficiently that the varnish may dry immediately on it when applied by the brush, care being taken that the brush is not too much wetted. There should be no hissing sound when the brush is applied, otherwise the coating will contain bubbles and the glass may even crack. The varnishing should first be practised upon a few broken pieces of glass, so as to obtain a correct estimate of the proper temperature required. Avoid drawing the brush over places already varnished, or they will get spoiled. If the coating is a failure, remove it by rubbing the whole over with a cloth dipped in spirit of wine. A solution of sealing-wax in spirit of wine is often used for the same purpose as the shellac-varnish, but such a coating does not look so well, being opaque and dull. If used, the solution must be stirred before being applied, since the heavier substances of which sealing-wax is made, sink to the bottom when left to stand. The shellac-varnish should be purchased, not made; it dissolves far too slowly and forms lumps in the liquid.

Shellac is a first-rate insulator, and it condenses much less vapour

on its surface than most kinds of glass; the varnish coating is specially intended for preventing the condensation of vapour.

Electricity is also produced when conductors are rubbed, but as the conductor is usually held in the hand while being rubbed, the electricity produced escapes as fast as it is generated. A conductor must hence be insulated before the electricity produced by rubbing it can be observed.

Upon a stick of ordinary sealing-wax a smooth copper coin is fastened; holding the end of the sealing-wax between the thumb and forefinger of the right hand, the coin is rapidly yet softly moved across a piece of fur spread out in the palm of the left hand, the motion resembling that used for cleaning a painter's brush; a single stroke is enough to render the coin sufficiently electrical to attract the cork ball suspended by the linen thread at a distance of 1 or 2^{cm}.

45. *Induction. The Electroscope. The Electrophorus.*—A special class of phenomena is observed, when an electric body is brought near to an unelectric insulated conductor, but not so near as to cause a spark to pass between the two bodies or electricity to be transmitted in any other way. These phenomena may be best studied by means of a conductor consisting of two halves, which can be removed from one another, for example, two coins insulated by being attached to sticks of sealing-wax. One of the sticks is fixed below to a small board, so as to stand vertically, the coin being in a horizontal position at the top. The other stick is held in the left hand, so that the edges of the two coins are just touching, while a rubbed glass rod is brought near to them with the right hand, as in fig. 304. Since

the electrified body must be brought as near as possible, yet without losing electricity by transmitting it to the two metal discs, it is necessary to ascertain by preliminary experiments how near to the discs the glass rod may be brought without direct transmission of electricity. Care being taken that the two discs touch one another while the glass rod is near them, the glass rod

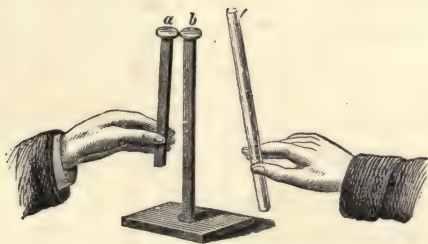


FIG. 304 (*an. proj.*; $\frac{1}{2}$ real size).

is removed, and each of the discs tested by bringing it near to the electric pendulum: neither of them should manifest electricity. By several successive experiments the *least* distance between discs and glass rod is thus determined at which no transmission of electricity takes place.

The excited glass rod is now again brought near to the two coins, which are touching one another, but this time the disc *a* in fig. 304 is immediately after the approach of the glass rod removed to a distance of a few millimetres from the disc *b*, and the glass rod itself is then put away altogether. Both discs are now successively brought near to the electrical pendulum, which has a *conducting* suspension (cotton thread); *both* will be found to be charged equally strongly. In order to ascertain the kind of electricity with which

they are charged, positive electricity is communicated to an electrical pendulum with *insulating* suspension (silk) by touching it with a rubbed glass rod; repeating the experiment, the disc *a* will be repelled by the pendulum, and the disc *b* will be attracted; in other words, *a* is positively charged and *b* negatively.

The experiment being repeated several times, the fact will be established beyond doubt, that if two metallic discs are in contact, and near an electric body, they will become charged with opposite electricities, provided, first, that they are separated by a small distance after the electrical body has been brought near them, and second, that after their contact has ceased the electrical body is removed. If after removal of the excited glass rod the two metallic discs are allowed to touch one another and then tested with the conducting pendulum, neither of them will manifest a trace of electricity.

These experiments show how two bodies may be charged with opposite electricities, and the last experiment proves the important fact that equal quantities of opposite electricities *neutralise* one another; or in other words, bodies which contain equal quantities of *both* electricities behave exactly like unelectric bodies.

No electricity has in these experiments been directly communicated by the glass rod to the discs; the mere approach of the excited glass rod was sufficient to produce opposite electrical states in them, and we are therefore justified in conceiving that each of the discs was in fact, previous to the approach of the glass rod, charged with electricity, but in such a manner as to be incapable of manifesting it; further, that the electricity

with which each disc was charged was of *both* kinds, each kind being present in equal quantity and both therefore neutralizing one another; finally, that the action of the excited glass rod was nothing else but to effect a *separation of the two electricities* and to distribute them over the discs in such a manner that by a suitable mode of procedure each kind of electricity may be rendered manifest. We may, indeed, go a step farther and say, every unelectric body contains both electricities in equal quantities.

The term 'opposite' electricities originates solely in the fact that the two electricities neutralise one another in their effects, for a positively charged body behaves exactly like one charged negatively. The algebraical signs $+E$ and $-E$ being often taken to represent a positive or a negative electric charge respectively, a body in the unelectric or neutral state may in accordance with the above conception be designated as containing $\pm E$.

This action of an electrical body upon neutral bodies at a distance, whereby it 'induces' in them the electrical state, is called *electrical induction*. The electrical body and its electricity, as in our case the glass rod and its positive charge, are often respectively termed the 'inducing body' and the 'inducing electricity,' while either of the electricities separated by induction may be called 'induced electricity.'

It is not difficult to explain the phenomena observed in the preceding experiments. The approach of an electric body to a neutral one, that is, to a body containing both electricities, effects their separation simply because the electricity of the first body attracts that

electricity of the neutral body which is of the opposite kind, and repels that which is of the same kind. If the neutral body is a conductor, the electricities move easily in obedience to the attractive and repulsive forces which come into play. The electricity of the same

kind as that of the inducing body moves to the more remote part of the neutral body, while the opposite electricity moves to the nearest part. Thus, let fig. 305 *A* represent the electrical state of the two discs before the glass rod is brought near them. If the positively charged glass rod is brought near from the

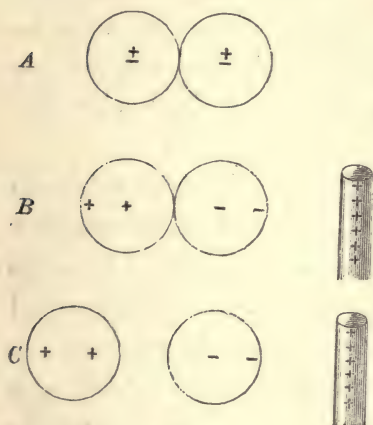


FIG. 305.

right side the negative electricity of the discs is attracted by it and moves towards the disc on the right side, while the positive electricity is repelled towards the left disc; this is shown at *B*. If the glass rod is removed while the discs are in contact, the neutral state represented at *A* is again restored, and both metallic discs are unelectric, but if they are separated while the glass rod is still in their neighbourhood, as indicated at *C*, a union of the two electricities cannot take place after the glass rod is removed, and on testing the discs they are found to be charged with opposite electricities; finally, if brought into contact after removal of the glass rod, the original neutral state of the discs is again restored.

The electricities separated by induction manifest a very different behaviour when the conductor in which the separation has taken place is touched by the finger, or is, by means of a wire or otherwise, conductively connected with the ground. When a conductor is charged by simple contact with a rubbed glass rod, it loses its electricity immediately when placed in conducting communication with the ground. Electricity which can thus be removed from a body is called 'free.' On the other hand, of the two electricities induced in a conductor by induction, only the electricity of the same kind as that of the inducing body can be removed while the influence of the inducing body lasts; the electricity which is of the opposite kind cannot be removed by conduction, and is said to be 'disguised' or 'bound.'

Let an excited glass rod be brought near to the disc, which is fastened to the top of the stick of sealing-wax on the wooden support. The electrical separation which takes place in that case is shown at *A* in fig. 306. If, while the glass rod is near, the disc be touched by the finger the free positive electricity is discharged as represented at *B*, while the negative electricity is in

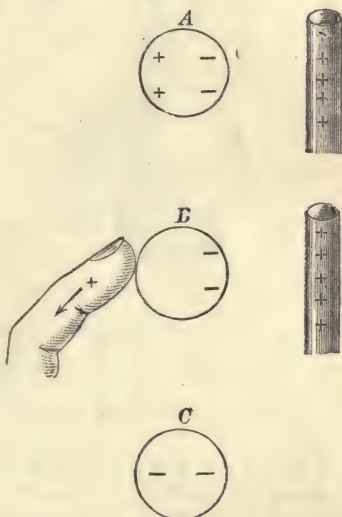


FIG. 306.

the bound state and remains in the disc. If now the glass rod is taken away, the attraction between the positive electricity of the rod and the induced negative

charge of the disc ceases, and the negative electricity of the disc becomes also free and escapes through the finger, if still in contact with it; but if the finger is removed before the glass rod, the negative free electricity of the disc cannot escape, and the disc is charged with free negative electricity, when the glass rod is removed. This state is indicated in *C*, fig. 306.

Induction plays a most important part in a great many phenomena of electricity. On it depends also the action of the gold-leaf electroscope and of the electrophorus.

The *Gold-leaf Electroscope* consists essentially of a metal rod terminating at its upper extremity in a knob

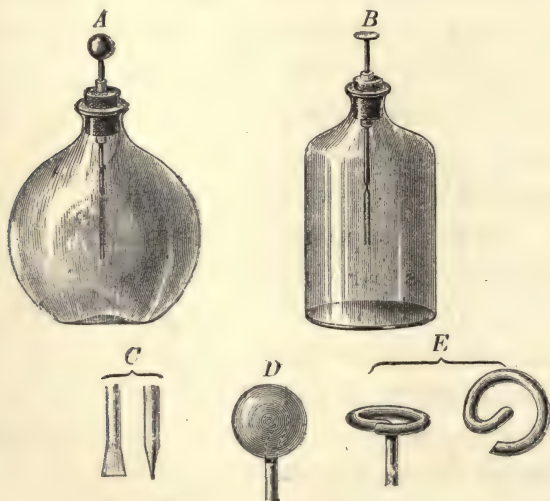


FIG. 307 (*A, B*, $\frac{1}{4}$ real size; *C, D, E*, real size).

or a disc and carrying at its lower end two narrow strips of gold-leaf. The lower part of the rod is in the interior of a shade or bottle of glass, as shown in fig. 307, *A* and *B*.

The instrument serves for detecting the presence and determining the kind of electricity in any body, and as for both purposes only the metal parts come under consideration, the remaining parts of the instrument are left out in the following figures.

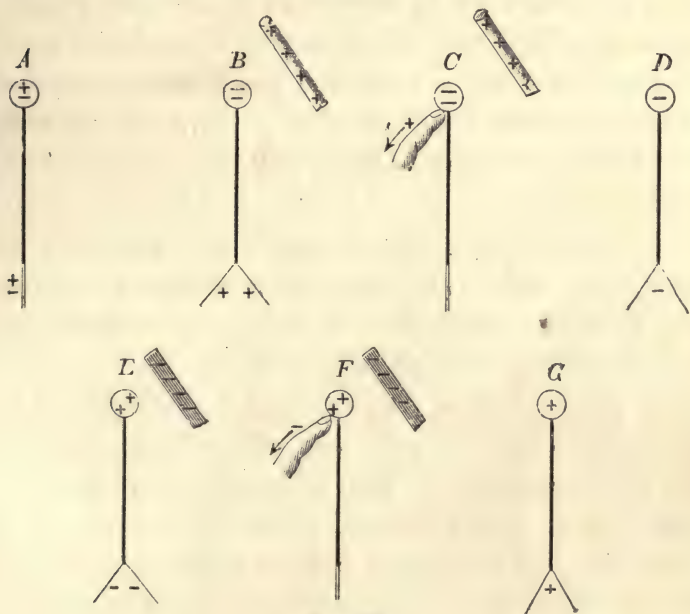


FIG. 308.

In the ordinary state the electroscope contains equal quantities of positive and negative electricity, as represented at *A* in fig. 308. When a body charged, say, with positive electricity, is brought near it, electrical separation is effected, the negative electricity being attracted to the knob, the positive electricity being repelled to the further extremity, that is, to the gold leaves. These are now electric, and being both charged with the same electricity, they repel each other, that is, being flexible, they *diverge*, as at *B*. When the in-

ducing body is removed, the leaves drop again because the two separated electricities recombine, and the electroscope is again in the neutral state *A*. If the metal rod is touched with the finger, while the inducing body is still near and the two electricities therefore still separated, then, as shown at *C*, the free positive electricity of the gold leaves escapes through the finger and the leaves drop, while the negative electricity of the knob remains bound as long as the inducing body is near the instrument. Now, while the inducing body is still near, let the finger be removed first, and next the inducing body; then the negative electricity becomes free, and as it cannot now escape, it diffuses itself over the metal portion of the instrument, and the gold leaves diverge again, as in *D*.

The electroscope is now charged by induction with the opposite electricity to that of the inducing body, that is, negatively, if the inducing body was, for example, a positively charged glass rod, and positively if the inducing body had been a negatively charged stick of sealing-wax. The latter case is represented in figures *E*, *F*, and *G*, which correspond to figures *B*, *C*, and *D*, respectively.

An electroscope, *charged* with either electricity, may be used not only for deciding whether a body is in the electric state or not, but also with what kind of electricity the body is charged. When a neutral body is brought into the neighbourhood of a charged electroscope as shown in *A* and *B* of fig. 309, no appreciable change takes place in the divergence of the leaves. In reality the divergence does diminish in that case slightly, because the electroscope itself acts now like an inducing body,

separating the electricities of the neutral body brought near it, and in consequence of mutual inductive action, a quantity of electricity of the opposite kind to that with which the instrument is charged, is repelled to the leaves, neutralising a portion of the original charge.

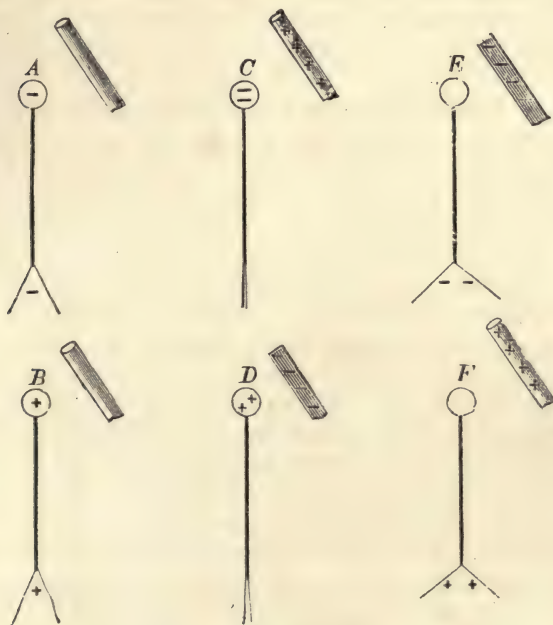


FIG. 309.

This action is, however, so slight, compared with the effects of a charged body, that no mistake can be made in the conclusions. If a body charged with opposite electricity is brought near to the instrument, as in *C* and *D*, the leaves drop because their charge is attracted to the knob. If a body charged with the same electricity is brought near, the charge in the knob is repelled to the leaves, and their divergence increases as in *E* and *F*.

A flask of hard glass with a short neck of the kind used for some chemical operations, will serve for constructing an electroscope. A piece of brass wire, from 8 to 12^{cm} long and 2^{mm} thick, is straightened, and softened at both ends in the flame; one end is hammered flat and shaped with a smooth file into the form shown at *C* in fig. 307. The other end is either bent into a small ring, *D* in fig. 307, introduced into a bullet mould and lead poured round it; or it is bent as shown at *E* in fig. 307, and a small round disc of metal soldered upon it. The bullet or the disc must have a perfectly smooth surface the bullet should be carefully cut smooth with a sharp knife; a worn small copper coin will serve very well for the disc. The brass wire must be well insulated by surrounding the portion which is in the cork with sealing-wax or still better with shellac. The wire is heated along that part until the wax or shellac melts upon it; a sufficient quantity is then placed upon the wire, and while it cools the whole is rolled between the fingers so as to form a cylinder about as thick as a common pencil. A hole is then bored in the cork into which the cylinder should fit tightly, and so that it projects a little beyond the cork on both sides.

Genuine gold leaf must be used; imitation gold leaf, which is made of brass, is too stiff for the purpose. It requires some skill to cut the required strips from a sheet of gold leaf; an unskilled hand wastes a great deal of material in the attempt, and it is therefore much better to have the strips cut and fixed to the flat end of the wire by a skilled mechanic. They are fixed by solution of gum arabic, or white of egg, of which a trace is spread upon both flat sides of the wire. They should be about 3^{mm} wide, and from 3 to 5^{cm} long, so that in no position they can reach the glass. In introducing the wire with the leaves every current of air must be avoided, or they will be blown aside and adhere to the glass, in which case it is impossible to separate them again without tearing them. It is advisable, if the student attempts the operation himself, to cover nose and mouth by a cloth.

The flask must be thoroughly dried before introducing the cork with the wire and leaves. Flasks with narrow necks may be dried in the following manner. After being thoroughly washed and rinsed with clean water, the flask is clamped mouth downwards in the retort-stand or placed with the mouth upon a piece of folded blotting-paper. After being kept in this position for an hour or two the greater portion of the adhering water will be removed; the flask is then held over the lamp, and constantly turned until it is as hot as the hand can just bear. A glass tube is now introduced which reaches to the bottom of the flask and air is blown into it,

in order to remove the greater portion of the vapour of water formed by the heating. When after repeatedly heating the flask and expelling the vapour, all *visible* moisture is removed, the flask is once more heated and the air *sucked* out of it for some time by means of the tube, in order to replace by dry air the moist breath blown in previously. As common water after drying off usually leaves a little solid residue on the sides of the flask, it is better to use either distilled water or pure alcohol for rinsing, if the flask is to be perfectly clean, as either of these liquids evaporates without a solid residue. If alcohol is used, the flask should be rinsed with it after having first used water and allowing it to run off; the alcohol will then be available for burning, as it is not rendered too dilute. The flask should be kept mouth downwards for a day after rinsing it with alcohol; otherwise too much alcohol remains behind, and its inflammable vapour may cause accidents while the flask is being heated.

The cork may be fixed with sealing-wax, which is placed in sufficient quantity along the edge of the flask and melted by the spirit-flame, using the blowpipe as in fig. 121, but directing the flame carefully upon the edge of the flask alone, not upon the middle, as otherwise the cylinder round the wire becomes softened, in which case the wire sinks to the bottom of the flask.

The instrument should only be charged by induction, for if charged by touching it with a rubbed rod of glass or sealing-wax, the charge may be too great and produce not only disturbances but also too wide a divergence of the leaves, which might tear them. Even when charged by induction care must be taken to bring the inducing body only so near that before applying the finger to the wire the divergence may not be greater than that in fig. 308.

When once charged the electroscope may be used for an hour or two, if the air is dry; but after that time the instrument must be charged again if further required. The body to be tested must be brought near the instrument very slowly, and the behaviour of the leaves must be observed from the moment when the body is brought near. If the body and the instrument are charged with the same electricity, the leaves diverge immediately; if the electricities are opposite the leaves will under all circumstances converge *at first*. When the body to be tested is strongly electrified and pretty near to the instrument, the leaves may possibly diverge after having converged on the first approach of the body, and uncertainty may arise, especially if the body is brought near rather rapidly, and the convergence of the leaves at first was not sufficiently close. The cause of the convergence is easily understood. In charging

an electroscope by induction, only a small portion of the two electricities which the electroscope contains in the neutral state are actually separated. Hence if, for example, the electroscope be charged negatively, and a strongly charged positive body be brought near to the knob, a further separation of the two electricities in the instrument takes place, and since all *free* negative electricity is attracted to the knob, there will be no electricity in the leaves when the body has reached a certain distance from the electroscope; the leaves now collapse. But when the body is brought still nearer, the positive electricity which is repelled to the leaves will cause them to diverge again. It is obvious that corresponding effects are produced in a positively charged instrument by a body with a strong negative charge.

By means of the electroscope it may easily be proved that two bodies which are rubbed together assume opposite electrical states. A round stick of sealing-wax, 12 or 15^{mm} thick, and from 15 to 18^{cm} long, is pushed with one end into a little bag of chamois leather 6 or 8^{cm} long, into which it fits exactly. To the closed end of the bag a thread of common sewing silk is fastened, which is about two decimetres long. Holding the bag in the left hand and turning the sealing-wax with the fingers of the right hand, the leather becomes positively charged, and the sealing-wax negatively. The bag is now pulled off by seizing the thread at the end of it and holding it suspended by the thread it is allowed to touch an uncharged electroscope. The instrument will become immediately charged as seen by the divergence of the leaves. If now, the charged sealing-wax be brought near the instrument, the leaves collapse, that is, the electricity of the sealing-wax attracts that of the leaves, which is identical with that of the leather bag, hence both are of opposite kind.

If after being rubbed the sealing-wax is left in the bag and both together brought near the instrument, no

effect is produced. Now since the previous experiment proves that bag and sealing-wax are really charged by the rubbing, and that their charges are of an opposite kind, the last experiment proves that both charges must be equal, for they neutralise one another exactly. As soon as the bag is pulled off, the two equal opposite charges manifest again the effects already described, and it is clear that in order to produce these effects local separation of the two electricities must take place first.

The *Electrophorus* is an instrument for generating

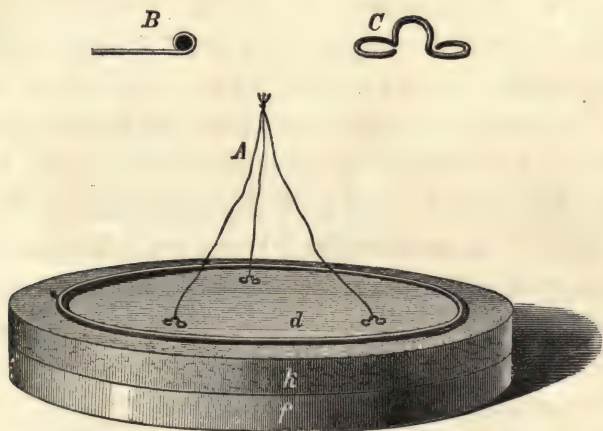


FIG. 310 (*A, C, an. proj*; *A, $\frac{1}{3}$ real size*; *B, C, real size*).

in a simple manner by induction a somewhat greater supply of electricity. It consists of a conducting support, *f* in fig. 310 *A*, called the *form*, upon which is placed a circular disc of some substance which is easily electrified by friction, usually a cake of resin or a disc of ebonite, *k*. Besides this there is a metal disc, or 'cover,' *d*, to which are attached three insulating threads of silk, tied together at one end, by means of

which the disc may be raised from the cake. The cake is electrified by briskly flapping it in an oblique direction with a piece of fur, for example, a cat-skin or a fox-tail. If the cover is now placed upon the excited cake and touched with the finger, a small spark passes between disc and finger. If next the cover be raised by the silk threads, it is strongly electrified, and if a conductor be brought near it a smart spark passes. When the cover is afterwards replaced upon the cake, touched, and again raised, it is found to be again charged, and the whole may be repeated many times without electrifying the cake again.

The electrical state of every part of the electrophorus may be investigated by means of the 'carrier' or 'proof-plane,' a small piece of metal attached to the end of a slender rod of some non-conducting substance. If the rod is held by the hand and the conductor at the end of it applied to an electrified body, a small quantity of electricity is communicated to the proof-plane and the latter may be brought near to an electroscope instead of the electrified body itself.

Let the cake be briskly flapped, and the excited surface be held over an electroscope which is charged with electricity of a known kind, the motion of the gold leaves will indicate that the cake is negatively charged. The cake is now replaced upon the form and flapped again, in order to make up for the loss of electricity which happened during the first experiment, and the metal disc placed upon it, taking care to hold it by the strings and not to touch it. When the disc is again lifted by the strings and brought near to an electroscope, no electrical indication is observed, which proves that

no sensible quantity of electricity has been communicated by the cake to the disc. But if the disc while it rests on the cake be touched but for an instant with the finger, it will give strong indications of positive electricity if raised and held even at some distance from the electroscope.

The two electricities of the cover are separated by induction when the cover is placed upon the negatively charged cake ; the positive electricity is attracted to that side of the cover which is in contact with the cake, while the negative electricity is repelled to the upper side of the metallic cover. That the upper surface is really charged with free negative electricity may be proved by touching it (before the finger is applied) with the proof-plane and bringing the latter near an electroscope. When the upper surface is touched with the finger, the free negative electricity passes off and the cover remains charged with positive electricity, bound, however, by the negative electricity of the cake ; again, if the cover is raised by the insulating cords, the positive charge is no longer attracted by the negative of the cake, it diffuses itself over the cover, and if a conductor be brought near it, a smart spark passes.

When the cover is raised before being touched by the finger, the two electricities simply combine again and the cover can give no indication of electricity.

The metallic form upon which the cake rests increases the quantity of electricity and makes it more permanent. The negative electricity developed on the upper surface of the cake acts inductively on the lower, attracting the positive electricity but driving the negative into the ground. The attraction of this positive electricity binds

in its turn the negative electricity of the surface of the cake, and thus prevents the dissipation of the charge which takes place while the cover is removed, in consequence of the access of air, which acts as a conductor. As long as the cover is on, it obviously excludes the air, and the mutual action of cover and cake is preserved.

The form and the cover should be made by a tinsmith, the form of tin and the cover of sheet zinc or brass. The form is a flat round mould 20^{cm} in diameter and 1^{cm}·5 deep; the cover is a round flat disc, 16^{cm} in diameter, with a solid rim which is formed by bending the edge all round over a stout wire, as shown in section at *B*, fig. 310. Much care must be taken to make the disc perfectly flat and the rim nicely round and smooth. Small loops of the form shown at *C* in the figure, made of brass-wire 1^{mm} thick, are soldered at three points equally distant from each other, and 2^{cm} from the edge. To each loop one end of a thin cord of silk is tied, each cord being 15^{cm} long, and the other ends are joined by a common knot. The cords must be of pure silk, perfectly free from cotton, or they will not insulate properly. If pure silken cords cannot be obtained, three or four threads of common sewing silk may be used instead of each cord. Or loops and cords may be altogether dispensed with by attaching an insulating handle to the disc; it is first heated and the end of a stick of sealing-wax pressed upon it. The sealing-wax handle is more convenient than the cords but is rather easily broken.

The melted resinous matter for the cake must not be poured *into* the tin mould. The latter is placed bottom upwards upon a steady even table and surrounded by a rim of paper. A few strips of stiff writing paper, 3^{cm} wide, are pasted together at the ends so as to form a strip 70 or 80^{cm} long, which will pass more than twice round the form. It is laid tightly around the rim, so as to project 1^{cm}·5 above the bottom of the form and the end is fixed with gum. Forty grammes of yellow bees' wax and 40 grammes of turpentine are next heated in an earthenware pot of about 1 litre capacity. Turpentine, which must not be confounded with oil of turpentine, is a thin resinous liquid, of which two sorts are usually sold, the common and the Venice turpentine; the former, which is inferior, will do for our purpose. The heating should be very slow and gradual, or the pot will crack, and the mass should be constantly stirred with a splinter of wood. When all the wax is melted, 400 grammes of shellac are added in small portions, each time about a handful of the thin scales

of which unbleached shellac consists. Care must be taken, by constant stirring, that the small lumps which are formed on each addition, should quickly dissolve in the liquid mass; as soon as each lump is dissolved more shellac is to be added, for if too much time is lost the liquid becomes too hot and then forms a mass resembling india-rubber, which cannot be again liquefied and is therefore useless. When all the shellac has been added, the pot is removed from the fire, the mass once more briskly stirred so as to render its consistence quite uniform, and to remove from the surface any film of melted wax, and the whole is poured into the mould formed by the rim of paper. After a few hours, when the cake is quite cold, the paper is torn off as far as possible, and the cake lifted from the form; if it adheres in some places, the metal is slightly pressed from below and the flexure of the metal will help to free the cake. The utmost care must be taken not to drop it, as it is rather brittle and easily broken. The paper which has not come off at first may be removed by wetting it and rubbing it off with the finger, or it may be left on without disadvantage.

In using the electrophorus, the form is placed beneath the cake in the way just described, that is, bottom upwards, and the cake is placed upon it so that the flat side which was in contact with the form when the cake was moulded, is now uppermost. Formerly, the form was used differently, its bottom resting on the table, the cake was poured into the interior, hence its name 'form.' But the cake, when firmly imbedded in the mould, is sure to crack after some time, while a loose cake lasts indefinitely if carefully handled. If it should break, it may be recast; after breaking it into small fragments these are melted in the same pot which served originally, and which should be kept for this use, as it cannot be well cleaned and used for any other purpose. The mass must again be constantly stirred until it is uniform, before pouring it into the form.

For the experiments the cake must be quite dry, and if possible slightly warmed, not so much, however, as to make it soft. During the winter care should be taken to warm it slowly, otherwise it is liable to crack. It is best warmed by holding it at some distance before an open fire. While striking the cake a few fingers of the left hand are laid upon the edge, so as to prevent its sliding from the form while the cat's fur is applied with the right hand. If a fox's brush is used, it is held at the thicker end and the strokes are applied quite slanting; a cat's skin is held by the projecting points, so that the furry side is outwards, and the cake is struck similarly, not strongly, but so that the fur may briskly glide over the whole surface of the cake. In dry air the cake will remain electrical for

several weeks, when the cover is kept upon it; nevertheless, if an energetic action is desired, it should be electrified again each time it is used.

The cake should always be kept upon the form so that no portion of the edge may project, for such projecting portions are apt to become bent downward during the heat of the summer, although the cake does not appear sensibly soft. In the summer the cover should not be kept upon the cake, or it may possibly sink by its own weight some little distance into it.

The spark obtained from the cover while it rests upon the cake produces a very sensible effect, when one finger is placed upon the form and another finger, either of the same or of the other hand, is brought near the cover. To obtain smart sparks from the raised cover the experimenter must take care lest his clothes should come too near the cover, for projecting points such as form the rough surface of clothing diminish the quantity of electricity in electrical bodies, as will be seen later on. For the same reason all other bodies should be removed as far as possible from the electrophorus.

When a rough body, for example, the knuckle of the finger, a file, or a small piece of wood, is brought near, especially if the approach is slow, several small sparks are obtained from the raised cover; these sparks are scarcely visible and hardly audible, but very bright and audible sparks are obtained if the body employed is a metallic conductor well rounded at the end brought near; the round handle of a pair of scissors, or still better, a brass ball soldered to a stout wire, such as forms part of various electrical apparatus, are very serviceable for this experiment.

The sparks obtained from the edge of the cover are somewhat longer than those obtained from the more central portion, but they are less audible and bright. An electrophorus of the given dimensions should in dry weather give sparks 2^{cm} long.

As carrier or proof-plane a common toy-marble of glass or stone, 1 or 1^{cm}·5 in diameter, may be used; it is attached to an insulating handle and then provided with a well-conducting surface by covering it first with a layer of gum and then with goldleaf. The insulating handle is made of a small stick of shellac or sealing-wax, 4 to 8^{mm} thick and 8 or 10^{cm} long, formed by rolling soft shellac or sealing-wax between the fingers; it may also be made from the substance of which the electrophorus-cake consists, by scraping with the splinter of wood a sufficient quantity from the sides of the pot. The knob is heated until the end of the little stick melts upon it; when cool it will remain fixed to it.

A metallic disc fixed to the insulating handle will also serve as

a carrier. Either a round disc of sheet brass, 15^{mm} in diameter, of which the edge has been filed very smooth all round, or a small copper coin, worn quite smooth, may be used for the purpose.

Very instructive phenomena are produced by electrical induction in a jet of water. A small fountain is constructed like those in figures 141, 170, or 175, and

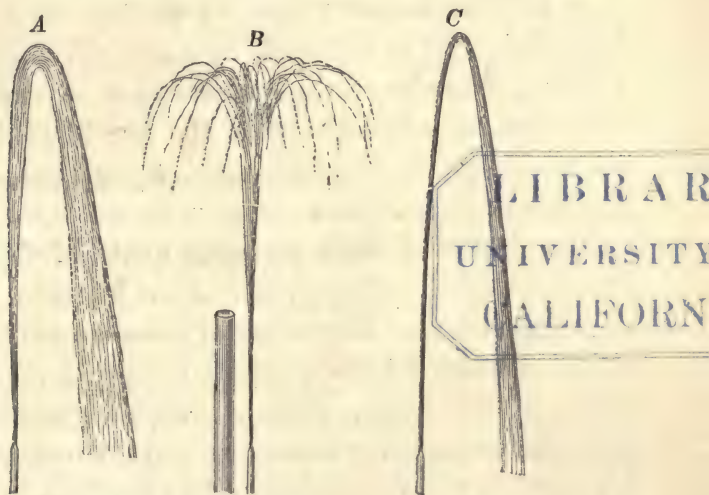


FIG. 311 ($\frac{1}{5}$ real size).

an excited rod of glass or sealing-wax held at a distance of a few centimetres from the clear portion of the jet which is the nearest to the orifice from which the jet issues.

Under ordinary circumstances the jet consists of three portions. Close to the orifice it appears as a transparent cylinder, like a rod of glass. In the next portion it appears still as an uninterrupted liquid cylinder, but it has lost its transparency; this portion consists of an infinite number of single drops, succeeding one another very rapidly. In the third portion the drops are visibly separated, as in fig. 311 A. When

the electrified body is brought near, the separation of the drops takes place at the end of the clear portion of the jet and the drops are scattered in wide-spreading arcs, as in fig. 311 *B*. The drops manifest mutual electrical repulsion, and if some of them are allowed to fall upon the proof-plane or a larger sheet of metal (5 or 10^{cm} in diameter) fixed to an insulating handle, their electricity as indicated by a charged electroscope will be seen to be of the opposite kind to that of the electrified body brought near the jet; if sealing-wax has been used, the drops are positively charged; if glass, they are negative.

The electrified body produces electrical separation, by induction, over that portion of the jet which forms a connected whole. Electricity of the same kind as that of the electrified body is repelled towards the body of water in the vessel, while the opposite electricity is attracted towards the issuing jet and the drops, charged all with the same electricity, dart away from each other just at the point of the jet where the cohesion of the drops is becoming less and is therefore overcome by the force of electrical repulsion. Since each drop as it is torn away from the remainder carries its own charge with it, it may easily be tested; it is not so easy, however, to examine the electricity with which the water in the vessel becomes charged by induction, for although the vessel is of glass it becomes moist during the experiment and the charge is conducted to the ground. On the other hand, when the vessel is insulated, the experiment does not succeed so well; in that case the induced electricity which is of the same kind as that of the

inducing body cannot escape to the ground, and diffuses itself gradually over the whole liquid mass.

If the electrified body possesses only a weak charge or is held several decimetres from the orifice, the phenomenon is very different. The drops do not only not separate but remain even more closely together than in a common jet, so that even the descending portion appears to cohere, as in fig. 311 *C*. This phenomenon is particularly surprising because a small trace of electricity is sufficient to produce it. In order to explain this effect we must consider that the form of the liquid jet depends essentially on the nature of the liquid and of the substance of which the orifice is made. Thus glass is moistened by water, but not by mercury, and when under ordinary circumstances a jet of mercury issues from a glass spout its form is precisely that of *C* in fig. 311, because the glass is not moistened by the liquid and the cohesion of the mercury particles not interfered with. Such an interference happens, however, when water issues from glass: the glass is moistened by the liquid, hence the liquid particles which form the outside of the issuing jet lag behind the interior portion of the jet, are made to rotate, and hence thrown sideways. It follows that if the moistening of the orifice by the water jet is diminished by some cause, the jet assumes more nearly the form shown at *C*. Now this happens precisely when the inducing body has a weak charge or is held at some distance from the jet, for in that case electrical repulsion takes place at the orifice between the liquid and the glass which diminishes the adhesion between the two, and as a consequence the water issues as a jet of

mercury would issue from the same orifice under ordinary circumstances.

To prevent the insulation of the glass vessel, a wire should lead from the inside of the vessel to the table or to the ground. The cohering jet may be produced by rubbing a piece of sealing-wax, not more than 2^{cm} in size, against the coat-sleeve, and then bringing it near the jet. A rod of glass which is strongly electrified effects the cohesion of the jet easily at a distance of 1^{cm}. The spout should be kept slightly inclined during these experiments, so that the descending water may not interfere with the ascending jet.

46. *Distribution of electricity upon conductors. Electrical Machine.*—Fig. 312 is a section of an insulated spherical conductor of sheet brass, fixed upon a glass rod provided with a wooden support. There are two openings in the ball, one horizontal which passes right through, and one vertical which leads from the top to the middle of the sphere.

The ball is electrified by placing a rubbed glass rod upon the top of the ball and drawing it over its surface, taking care not to touch the ball with the hand. When the glass rod is strongly electrified, it is sufficient to draw it once over the conductor; otherwise this should be done two or three times, having rubbed the glass rod each time again.

The conductor is now touched at some point with the proof-plane, and the latter brought in contact with an electroscope. Observe how far the gold leaves diverge, and remove the charge of the electroscope by touching it with the hand. Bring the proof-plane in contact with another point of the conductor, communicate the charge again to the electroscope, and the divergence of the leaves will be the same in the second experiment. It follows that the conductor was equally strongly electri-

fied at both points. Whatever points of the surface are investigated in this manner, the result will be the same: the electricity is uniformly distributed over the whole surface. It must, however, not be forgotten in

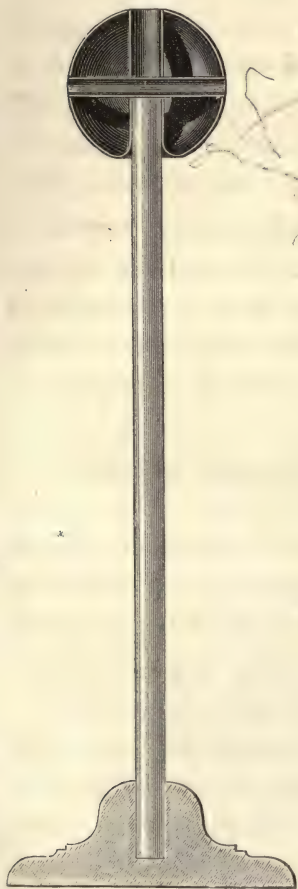


FIG. 312 ($\frac{1}{5}$ real size).

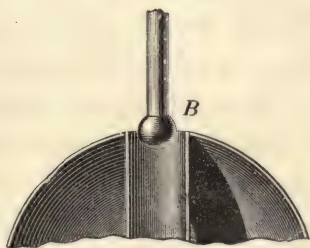
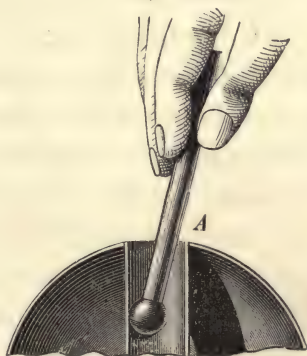


FIG. 313 ($\frac{2}{5}$ real size).

repeating the experiment very often in succession, that the divergence becomes smaller and smaller, because not only is a certain quantity carried away each time

by the proof-plane, but the conductor also in time loses its electricity even if not touched by the proof-plane.

Now let the interior of the conductor be touched by the proof-plane, applying it within the upper opening as shown at *A* in fig. 313, taking care not to touch the conductor with the hand and to withdraw the proof-plane without coming too near the open edge (see *B* in the figure). On touching the electroscope with the proof-plane no trace of electricity is indicated. The interior of the conductor is not electrical. To prove that this is not due to the fact that the conductor was originally charged from the outside, touch the outside by the proof-plane, apply the latter, which is now electrified, to the interior of the opening, withdraw it again, and test its state by the electroscope. No trace of electricity will be discovered: the electricity of the proof-plane has passed from within to the outside and has diffused itself over the external surface.

Thus in an insulated conductor the electricity resides solely upon the external surface. This is readily explained by the mutual repulsion of like electricities. Every small quantity of electricity which forms a portion of the total quantity with which the conductor is charged repels, and is repelled by, the remainder, hence a general rush to the farthest points, that is to the surface. This tendency of electricity to escape, caused by electrical repulsion, is called electric *tension*.

The electric tension on the surface of a spherical conductor is uniform in every part, simply in consequence of the symmetrical shape of the sphere. It is different with bodies of irregular shape. An elongated conductor may be formed by introducing a brass wire,

3^{mm} thick and 40^{cm} long, having one end pointed while the other is bent into a ring of 2^{cm} diameter, into the horizontal tube of the brass conductor, the pointed end of the wire being within. The whole is fixed in the conductor by pushing the wire through two small bits of cork which are cut so as to fit easily into the tube.

When the conductor is now charged by a rubbed glass rod, and the electricity of the ball and ring separately tested, the charge of the ring will be found to be stronger, for the divergence of the gold leaves is greater when the proof-plane is charged by contact with the ring than it is when charged from the surface of the ball.

The total quantity of electricity on the ball is much greater than that upon the ring, but the former has a larger space over which it can diffuse itself and is therefore less squeezed together than the electricity of the ring, which although small in quantity is strongly repelled towards the extremity of the ring by the large quantity of electricity on the ball, hence the electricity of the ring is much more crowded, and possesses a greater 'density.' The denser the electricity, the greater the mutual repulsion, and hence the greater becomes the tendency to escape, that is, the tension. It follows that on touching the ring with the proof-plane more electricity passes into the latter than when it touches the ball.

In general, in an elongated conductor the electricity is repelled most strongly towards the extremities and manifests there the greatest tension. If one extremity is more pointed than the other, as in the case of the ring and the ball, the tension is greater at the sharper end,

and the greatest tension is obtained when the extremity of the conductor is an actual point.

Move the two corks upon the wire nearer to the ring and push the wire into the tube so that the ring may be in contact with the ball. Arrange the electroscope upon some support so that its knob may be 30^{cm} from the point of the wire, and charge the conductor strongly by drawing the rubbed glass rod repeatedly along its surface. The gold leaves will diverge. Discharge the conductor by touching it with the hand. The divergence becomes smaller but does not disappear altogether, although no electricity exists in the conductor. It follows that the electroscope has been charged and that the electricity must have passed into it from the point. Discharge the electroscope and place it by the *side* of the conductor, instead of opposite the pointed wire, with its knob 4^{cm} from the sphere and charge the conductor as strongly as in the previous experiment. The gold leaves will again diverge, but they will immediately drop when the conductor is again discharged. It follows that in the latter experiment no electricity has been actually transferred to the electroscope from the conductor; the divergence was solely a consequence of inductive action.

The density of the electricity at a point, and hence the tension, is so great that the electricity passes to the particles of the surrounding air; these become electrified and convey the charge of the point like so many intermediate conductors to surrounding conductors. This action proceeds gradually. If the finger or any other conducting body be slowly brought near the point until it touches it, the electricity of the conductor dis-

appears insensibly; but if the finger be brought near to the spherical side of the conductor, the electricity does not escape until the finger has arrived within a small distance, and then the greater portion of the electricity escapes into the finger in one instant, as a spark large enough to be heard and seen, and often also to be distinctly felt.

The action of a point may also be shown if an electrified body is brought near a neutral body to which the point is attached. Let a fine sewing needle be fixed in a cork and the cork placed upon the electroscope, so that the point of the needle is directed upwards. If the electroscope has a round knob, the cork may be attached to it by making with the cork-borer a hole in the lower side of the cork, about 1^{cm} deep, into which the knob fits. When a rubbed glass rod is held about 20^{cm} above the point of the needle, electrical separation takes place by induction, in the same manner as it takes place in an electroscope without a pointed extremity; negative electricity is attracted to the point, and positive is repelled to the leaves. But if after a short time the glass rod is taken away without having touched the electroscope, the leaves will not collapse as they would under ordinary circumstances: the electroscope is charged. The nature of the charge may be investigated by pushing the cork off the knob, with an unelectrified insulator, for example a rod of glass or sealing-wax, so as to render the action of the point no longer possible, and bringing the rubbed glass rod which was used in the experiment near the electroscope. The leaves will diverge more widely, thus indicating that the electricity is of the same kind as that of the glass rod. The elec-

tricity of the opposite kind which had been attracted to the point has escaped at the point and passed to the glass rod, of which it partially neutralised the original charge, being of the opposite kind. The whole charge of the glass rod is, however, not neutralised under these circumstances, because the quantity of electricity which escapes at the point is, at the distance at which the glass rod is held from it, much smaller than the quantity in the glass rod; but if the latter is brought into the close vicinity of the point, its charge may be completely neutralised. If the spherical conductor is strongly charged, and the point of a needle which is held between the fingers is brought to within about 1^{mm} of it, scarcely the faintest spark will be obtained when the conductor is afterwards touched with the finger; on the other hand, if no point be previously brought near and thus allowed to neutralise the charge of the conductor, a smart spark will be obtained from the conductor if the finger is brought into contact with it.

The point attached to the neutral body becomes electrical by the inductive action of the electrified body near it. Its electricity is of the opposite kind and the dispersive action of the point causes it to be rapidly transmitted to the electrified body, where it partially neutralises the original charge. If the neutral body is insulated, electricity of the same kind as that of the electrified body near it will thus gradually accumulate in it, and the ultimate effect will be that the point in this case appears to *collect* electricity, while, as we have seen, a point attached to an electrified body tends to *disperse* the electricity. Nevertheless both effects are due to the same cause, viz. to the dispersive action of

a point; in one case the point disperses the electricity with which the body is charged originally, in the other it disperses one of the two electricities which are separated by induction in the neutral body; in either case *points, whether attached to an electrified body, or only near it, diminish the original charge, or render it impossible or difficult to charge it properly.*

A few precautions are necessary for success in these experiments. The metallic conductor must be perfectly round and smooth; a rough surface and projecting corners act like points. The lower edges of the vertical opening of the conductor are therefore rounded off by being turned inwards, so as to avoid sharp edges, which would disperse electricity towards the support and the table. The glass rod which carries the conductor must be well rubbed down with a dry cloth, if it should not insulate properly.

For proving the equality of distribution on a sphere, its inequality when the sphere is connected with the wire, and the absence of electricity in the interior, it is quite sufficient to draw the rubbed glass once along the conductor; a stronger charge would cause so great a divergence of the gold leaves that it could not be further increased, and the difference between the quantity of electricity distributed over the sphere and that distributed over the ring could not be demonstrated by the difference in the divergence when electricity from both parts of the conductor is transferred to the electroscope by the proof-plane. Too strong a charge might also cause the upper edge of the vertical opening of the conductor to communicate electricity to the proof-plane while it is being withdrawn from the interior, and this charge might then be mistaken for one carried away from the interior of the conductor.

For the experiments on the action of points, the glass rod should be drawn over the conductor 5 or 10 times, having each time been rubbed again. The spark given by the conductor on bringing the finger near should be 1^{cm} long.

The experiments which prove that electricity diffuses itself only over the surface of a conductor, may also be performed by means of a conical gauze bag, the opening being formed by a wire ring, fig. 314. The ring, which is 10^{cm} in diameter, is formed of brass-wire, 2 or 3^{mm} thick, and has a handle 10^{cm} long, the end of which is heated and fused into a stick of sealing-wax so as to insulate it. During the experiment the sealing-wax is clamped in the retort-stand, the foot

of which is weighted by some heavy object to prevent its being upset; or it may be fixed by a screw clamp to the edge of the table. The net should be 20 or 25^{cm} long; it may be starched so as to make

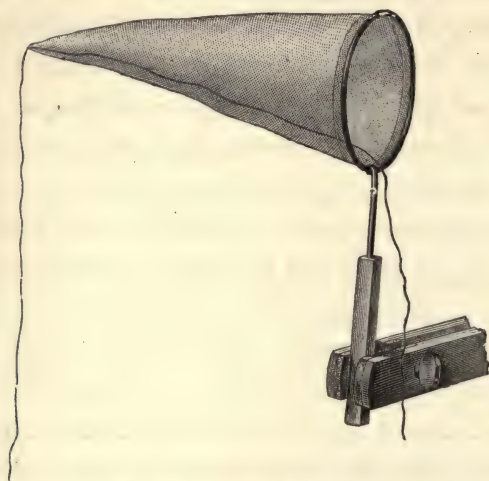


FIG. 314 (*an. proj.* $\frac{1}{2}$ *real size*).

it somewhat stiff. Two threads of pure silk are tied to the point of the bag, each 40^{cm} long, one being inside, the other outside.

After electrifying the bag it is seen by means of the proof-plane, that the electricity is only on the exterior, and that there is more electricity at the point of the bag than anywhere at the wider portion near the opening, and that if the sides are reversed by drawing the point of the bag through the opening (without, of course, touching it with the fingers) so as to turn the bag inside out, the electricity will still be found only on the outside.

The experiments with the gauze bag must be made rapidly, because the charge is soon dispersed by the action of the numerous fine fibres of the fabric. The net must be starched before the silk threads are tied to it, as the starch would make the silk conductive.

On the action of points depend essentially various apparatus for generating and collecting larger supplies of electricity, called *electrical machines*. The essential parts of a machine in which the electricity is generated by friction, are the 'rubber,' a cushion of leather or silk,

so mounted that a body of glass or ebonite revolving on an axis may be easily and rapidly moved against it; a row of points attached to a brass rod collects the electricity produced in the revolving body, and communicates it to the 'conductor,' a body with a metallic surface on which the electricity accumulates.

Fig. 315 shows the arrangement of these parts in a machine known as 'Winter's electrical machine.' A stout circular glass-plate, *g g*, is supported between two pillars, *t t*, by an axis, *a a*, of glass passing through the centre, which is turned by means of the handle *k* in the direction of the arrow. The plate revolves between two rubbers which are placed in a wooden frame *r*, on each side of it. The edges and corners of the frame are rounded off, and it is insulated upon a pillar of glass. Attached to the wood of the frame is a sphere of metal, from which, on approaching the finger, sparks of the negative electricity generated in the rubbers may be drawn. The conductor *c* is a hollow sphere of brass, the interior of which is exactly like that shown in fig. 312. The stalk of a small brass ball fits into the left horizontal opening, while the right opening serves for the attachment of the collecting apparatus *s s*, which consists of rows of points, placed inside of two wooden rings in grooves; the rings are connected together and with the conductor by a bent piece of brass. To prevent the electricity of the plate from discharging itself into the air before reaching the prime conductor, each rubber has a non-conducting wing of silk fastened to it. When the machine is in action, electrical attraction makes them adhere to the plate.

As the plate is turned, negative electricity is developed on the rubbers and led to the negative conductor, while positive electricity is formed on the glass and is collected by the points, which transfer it to the prime

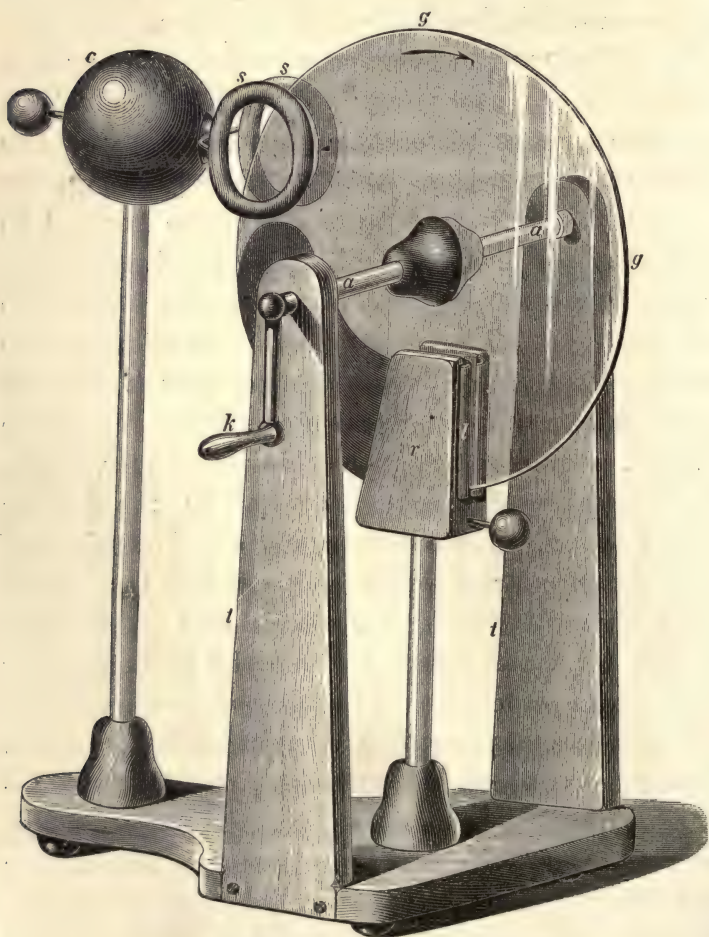


FIG. 315 (*an. proj.*, $\frac{1}{6}$ real size).

conductor. This is, however, not a complete account of what happens; in reality the conductor becomes

charged with positive electricity by induction from the glass plate, the induced negative electricity being discharged through the points across the intervening air to the plate and neutralising its positive electricity.

The rubber as it appears when seen from the left side of fig. 315, is represented in fig. 316 *A*. The wooden block has a rectangular piece cut out of the middle and is open at the top, so that the plate may pass through it without touching the wood.

Within this frame, on each side of the plate, is a cushion, consisting of an oblong wooden board, to which a piece of thick soft felt is glued. On the outside of each board, between it and the frame,

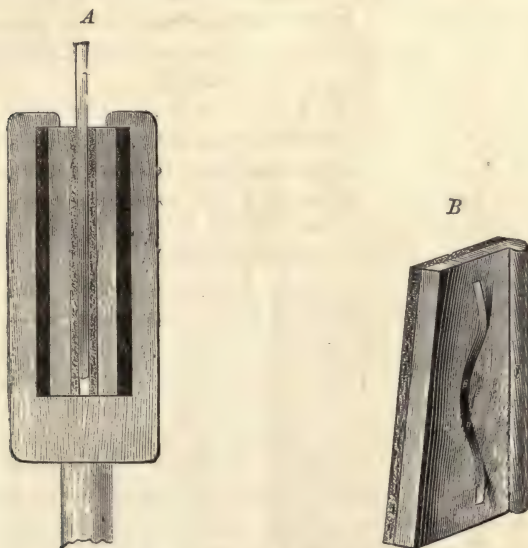


FIG. 316 (*B an. proj.*; *A and B $\frac{1}{3}$ real size*).

there is a metal spring which presses the board with moderate force against the glass plate. As the plate turns, the rubbers are prevented from being forced out of the frame through the friction by projecting ledges which press against the frame when the plate is turned in the direction of the arrow. At *B* one of the rubbers is shown separately, *l* being the ledge, *f* the metal spring; the wing of silk attached to the rubber is left out in this figure. If the rubbers are to be taken out, it is only necessary to turn the plate in the opposite direction and they will come out of themselves. When

the rubbers are to be put in the frame, one is placed on each side of the plate, the two springs are pressed together, one with each hand at the same time, so as not to break the plate by onesided pressure, and in this manner they are pushed into their places. The felt of the rubbers must be covered with a thin uniform layer of amalgam, which is reduced to powder in a porcelain mortar (one of metal would be spoiled), or between two small boards, and rubbed into the felt with the finger. When the machine has been in use for a considerable time, the amalgam should be renewed, the old layer being previously scraped off with a knife. For the various experiments on electrical distribution previously described the conductor of this machine may obviously be used; for this purpose it is cautiously raised from the support, and the small brass ball as well as the collecting apparatus removed by turning the latter gently from right to left. The collecting apparatus when put on again afterwards must be carefully adjusted so as not to slant; the plane of each ring must be parallel to the glass plate.

For the experiments just alluded to it is better to support the conductor on a separate pillar of glass, provided with a foot. If this cannot be done, the conductor may be used on the machine, but must be turned round so that the horizontal opening which passes through it may be parallel to the axis of the plate, and not directed to the glass plate as it is usually. Lest the plate, by being accidentally turned, should become electrified, and then by its own state disturb the intended experiments with the conductor, it is better to remove the rubbers at least an hour before the experiments, so that the plate may resume completely its neutral state.

In using the machine all parts made of glass must insulate well, they must therefore be quite dry. When the machine is brought in the winter from a cold into a warm room, water is deposited upon it, and this must be completely evaporated before the machine can be used. The handle should never be turned while the plate is still moist, or water will be forced into the rubbers, from which it cannot be got rid of for a long time. To dry the machine it may be placed at some distance from an open fire, but it should be removed again for use. There is no particular advantage in having the air which surrounds the machine very warm; the action is best when the machine is slightly warmer than the air, because in that case there is the least tendency for moisture to be condensed upon it. The action is also very good in a cold dry room, provided that care be taken not to breathe upon the machine. The experiments with the machine, and all other electrical experiments, generally succeed

in winter better than in summer, because the air is drier in winter than in summer.

In any case it is well before the experiments to carefully rub the glass pillars which carry the conductor and the axis with a dry cloth which has been a little warmed before a fire.

The wooden board on which the machine is supported must be fixed to the table by a screw-clamp so as to ensure its remaining firm and steady while the handle is turned. The further the machine stands from other objects, the better; everything not absolutely required for the experiments should therefore be removed from the neighbourhood, especially bodies with rough or angular surfaces; also burning candles, for burning or glowing bodies act like points, their effect being even stronger. A lamp-flame within a glass cylinder has, however, not much more disturbing effect than the lamp itself would have without the flame. The electroscope should be placed, if possible, a few metres from the machine, to prevent its indications being influenced by the inductive action of the machine.

When the machine has been worked a short time, let the conductor be touched with the proof-plane, and some of the electricity of the conductor be conveyed by the proof-plane to the electroscope. The leaves will diverge, and if a rubbed glass rod be brought near it, the divergence will increase. The electricity of the conductor is hence of the same kind as that of the glass rod, that is, it is *positive*. Now let the proof-plane touch one of the rubbers, and be brought near to the positively charged electroscope, the divergence diminishes, hence the electricity of the rubbers is *negative*.

If the divergence, on first applying the proof-plane, is at once so great as to render its increase impossible, the quantity of electricity in the electroscope may be diminished by alternately touching it and the finger with the proof-plane.

To prevent error the negatively charged proof-plane must be brought *near* the positively charged electroscope *slowly*; for if it be brought near at once so as to touch the electroscope it may happen that the divergence increases instead of diminishing. This would take place whenever the quantity of negative electricity in the proof-

plane happens to be considerably greater than the positive of the electroscope, in which case the latter is neutralised by a portion of the former, and the remainder of the negative charge of the proof-plane, diffusing itself over the electroscope, causes a greater divergence of the leaves than the positive charge did before.

✓ If the rubber is connected with the ground by a conducting wire or small metal chain, vivid sparks may be drawn from the conductor if another conducting body is brought near it. A machine of the size represented in fig. 315 will give sparks 10^{cm} long from the small brass ball, and of about half that length from the conductor. That the sparks are longer when drawn from the smaller ball, follows from what has been proved previously, viz., that electrical tension is greater at a narrow projecting part of a conductor than at a part which has a comparatively flatter surface.

Similarly sparks of negative electricity may be drawn from the rubber, if the conductor is placed in conducting connection with the ground while the rubber is insulated. These sparks, however, are smaller. The reason is, that although exactly as much positive electricity is developed on the conductor as negative on the rubber, more negative electricity is dissipated in consequence of the rubber being much nearer to the wooden support of the machine.

To obtain large sparks the flat palm of the hand should be brought near the conductor; not the hairy exterior, because the hairs act like points and, therefore, diminish the electricity of the conductor. Still better is a rather large round body of metal, for example the convex side of a smooth tablespoon, which is held in the hand and brought near the conductor.

The best way of connecting either the rubbers or the conductor with the ground is to use spirals of thin wire, closely wound. They are provided with hooks made of somewhat stouter wire, and soldered to the ends.

When the machine is worked while neither conductor nor rubbers are in communication with the ground, the sparks drawn from the machine become gradually weaker, and even cease altogether. This is because friction does not create new electricity, but merely causes a separation of the two opposite kinds previously combined; there is, therefore, at each turn of the machine exactly as much positive electricity developed on the plate as there is negative on the rubbers, and if the rubbers are insulated they soon receive a charge of negative electricity which it is impossible to exceed, when the tendency of the opposed electricities to reunite is equal to the power of friction to separate them. It follows that a continued succession of sparks can only be obtained from either conductor or rubbers, if the electricity of the opposite kind is conducted away. When the rubbers communicate with the ground, the negative electricity disappears as fast as it is generated, and the positive of the plate remains to act by induction on the conductor in the manner already stated. Were the rubbers insulated and no sparks drawn from them, all development of positive electricity on the plate would obviously cease immediately, but in reality there is constantly some loss of electricity going on from the rubbers in consequence of the vicinity of the wooden supports.

If none of the quantity of electricity in the conductor is withdrawn, it reaches a point of maximum charge, at which negative electricity is no longer dispersed at the row of points. The consequence is that the plate no longer becomes neutral, that its positive charge cannot be augmented by friction, and that no further negative electricity can be developed.

The quantity of electricity which may be accumulated on a conductor depends on its size; more electricity is clearly required to produce a given electrical tension at any point of the surface of a large conductor than to produce the same tension on a small conductor. For a long spark, quantity as well as high tension is requisite, hence the sparks from a large conductor follow each other at longer intervals of time than those from a small one; but as each spark is due to a much larger quantity of electricity, they are louder and much more powerful.

The surface of the conductor may be increased by inserting in its upper opening a large wooden ring, shown in fig. 317, provided with a short handle. Wood is not a good conductor; the ring contains, therefore, a core of iron wire, which communicates at the end of the handle with the conductor. The wooden ring consists of two halves, with a groove in each; the iron ring is placed in the groove of one half of the ring, and the other half is glued upon it.

When the ring is placed upon the conductor, the sparks follow each other much more slowly than without the ring, but not only is their length and brilliancy considerably greater, but they are also louder and brighter and produce a stronger shock.

The forms of electrical sparks are best observed at night in a perfectly dark room. The bright, loud-cracking sparks from the large ball form always a single line, white or light blue, and mostly straight. The sparks from the small ball are usually of a reddish or violet colour, and have the form of a bush without leaves, with a short single trunk, branches, and twigs.

This is one form of what is called the *brush discharge*. If the machine works well, these discharges from the small ball take place spontaneously. The longer sparks obtained from the small ball when the ring is placed on the conductor, do not exhibit many ramifications; they resemble more the simple sparks obtained from the large ball, but differ from them in having a zig-zag



FIG. 317 ($\frac{1}{8}$ real size).

form, like flashes of lightning. Sometimes fine ramifications proceed from the angular points of the zig-zag line which forms the main track.

The discharge from a point is characterised by a faint light or *glow*. If a wire be placed in the upper opening of the large ball, a luminous point, or a very small glow is seen, and similar appearances present themselves upon bodies with rough or pointed surfaces

brought near to the conductor of the machine. The finger-tips of the outstretched hand, the ends of projecting hairs of the head, and many other objects, exhibit luminous points when at a distance of 1 or 2 decimetres from the conductor.

By allowing a discharge to pass through a series of small conducting bodies all separated by a very short distance from each other, sparks can be simultaneously obtained at all the intervals between the successive bodies. This may be well seen in the 'spangled tube' represented in fig. 318, *A*.

A glass tube, about $0^m\cdot5$ long and from 12 to 15^{mm} wide, is provided with a metal knob at one end and a

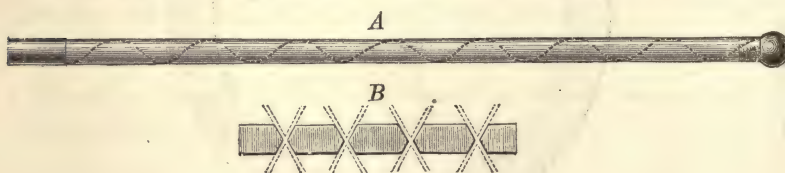


FIG. 318 (*A* $\frac{1}{5}$ real size, *B* real size).

ring of tinfoil at the other ; between the knob and the ring runs a spiral line of small bits of tinfoil, which are very close to one another. If the end with the ring is taken in the left hand, and the conductor of the machine is repeatedly touched with the knob while the machine is worked continuously with the right hand, a fine spiral series of sparks is obtained each time; if the wooden ring is upon the conductor, the sparks are more brilliant than without it. If the knob is left for some time in contact with the conductor while the machine is worked, small brushes instead of sparks are often obtained not only between the bits of tinfoil but also extending into the air, and near the conductor

the luminous spiral appears as if a fringe of delicate luminous filaments were attached to it.

A tube of suitable length and width being selected, the sharp edges at the ends are rounded off over the flame. When the hot ends have become cool again, the whole tube is moderately warmed and dried inside by drawing air through it. Both ends are then closed by tight-fitting corks, which are cut flush with the ends of the tube. A square piece of tinfoil is pasted round one end of the tube, a length of 1^{cm} being left to project beyond the end; this margin is afterwards folded over so as to cover the cork. Moderately thick starch paste is used, and the tinfoil covered on one side with a uniform thin layer of it. Only one edge of the strip of tinfoil is placed upon the tube at first, and pressed upon it by drawing the finger or a small plug of cotton wool along it; the remainder of the tinfoil is then gradually laid round the tube, rubbing constantly so as to make it firm and smooth. It is desirable to leave only a trace of paste between the glass and the tinfoil, yet the pressure applied should not be too great, or otherwise those portions which are already attached may be again displaced. The folds in the portion over the cork should be pressed smooth with a finger-nail, and a small disc of tinfoil, 3 or 4^{mm} narrower than the tube, may be afterwards pasted upon the end.

Several long strips of tinfoil 3 or 4^{mm} wide are cut with a sharp knife, using a ruler, and placing the tinfoil upon a sheet of zinc; the strips are pasted spirally round the tube, using isinglass for the purpose instead of starch. The tube must then immediately be carefully wiped quite clean with a damp cloth and left a day for the strips to become firmly attached. By means of double cross-cuts the strips are divided into a number of small hexagons, and the intervals between them cleaned from the adhering bits with a needle or the point of a knife. The mode of making the cross-cuts is indicated in fig. 318, *B*. The distance between two adjoining hexagons should be from 0.5 to 1^{mm}. In cutting, the sharp edge of the knife, *not the point*, must be used, otherwise the tinfoil will be torn from the glass in many places; no great pressure should be applied, as the glass soon blunts the knife without it; the hone should therefore frequently be applied.

The knob is formed of a brass ball with a short stalk which may easily be obtained from a dealer in electrical apparatus; the stalk is fixed in the cork, a hole of suitable size being made in the latter with a cork-borer. Care must be taken that the ball is in metallic communication with the end of the spiral near it. Brass knobs suitable

for the present purpose, as well as for several other electrical experiments, may be obtained by purchasing at an ironmonger's some 'upholsterer's studs' used for ornamental work, which are provided with screws or nails for attaching them; the small knobs used by trunkmakers as feet for boxes or trunks and sold at the ironmonger's by the name 'stoolballs' (see fig. 324, A, page 622), are especially useful. If such a knob be used in the present case, a hole must be made in the cork with the bradawl before the screw of the knob is worked in.

The discharge through points may be rendered very distinct by means of a wire several decimetres long, ending in a sharp point. The wire being placed in the upper opening of the conductor, with the point upwards, so much electricity is dispersed by the point that the conductor gives now much smaller sparks than before, their length being reduced to one third of what it was without the wire. If the wire is bent, so that the projecting portion is horizontal, and an electroscope is placed at a distance of 1^m or 1^m·5 from the point, the electroscope will become charged.

The electricity thus lost at a point is partially transferred to the particles of air near the point. These become electrified, and as their electricity is of the same kind as that of the point, electrical repulsion must take place. The particles of air fly away from the point, and a small current of air, the 'electrical wind,' is produced which proceeds from the point. By presenting to the point the flame of a stearine candle, which has a very short wick so as to reduce the size of the flame considerably, the flame will be directed aside when the machine is worked, and may even be blown out by the current of air.

The wire should be rather thick for these experiments, about 3^{mm}, so that it may not vibrate too much. It is fixed in a cork which fits pretty tight in the opening of the conductor.

The mutual repulsion between the particles of air and the point can be made to move the point itself. The 'electric whirl,' fig. 319, *A*, consists of an easily moveable cross made of very thin sheet brass, the ends, which are pointed, being all bent in the same direction.

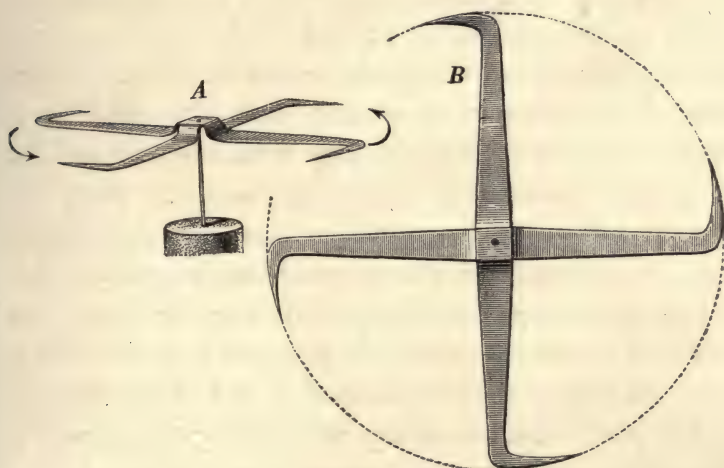


FIG. 319 (*A an. proj.* ; *A and B $\frac{1}{2}$ real size*).

When placed with the middle upon the point of a darning needle, of which the eye-end is fixed in a cork in the upper opening of the conductor, the arms revolve in the direction of the arrows when the machine is worked.

In a very thin sheet of brass a small cavity is pressed with the centre punch, and placing one point of a pair of compasses into the cavity as centre, a circle is drawn on the sheet with a radius of 5 or 6^{cm}. The cross is supported afterwards by placing the cavity upon the point of the needle. The cross is cut as in fig. 319, *B*. The arms of the cross, which become bent in the cutting, are softened over the lamp, straightened, and bent near the middle, as shown at *A* in the figure. The side which is uppermost in *B*, is obviously the lower one in the experiment. In cutting, care must be taken that clean edges are obtained ; any rough portions must be carefully filed smooth and even.

Many amusing experiments with the machine depend on electrical attraction and repulsion. A few of these deserve mention.

A wire, 35^{cm} long, is inserted in a cork which fits into the opening of the conductor. To the end of the wire a round disc of metal is soldered, 2^{cm} in diameter, to which are gummed about 12 or 15 strips of thin paper, tissue paper being the best for the purpose. These strips hang straight down, but when the machine is worked, repulsion takes place between the wire and the strips, and between the strips themselves. If an un-electrified body be brought near the electrified strips, for example the hand, the strips are attracted.

For the experiment called 'the dancing balls' the cover of the electrophorus is suspended by its strings from the arm of the retort-stand so as to be horizontal, and 5 or 6^{cm} from the surface of a table. A thin wire of suitable length is bent at one end into a hook, which is placed round the stalk of the small ball of the conductor, while the other end is placed upon the suspended cover, which is thus in conducting communication with the machine. Beneath the cover a number of pith-balls are placed. When the machine is worked the disc becomes charged and attracts the unelectric balls. By contact they become electrified and are then strongly repelled, but as soon as they again touch the table they give up their electricity, and are again attracted upwards by the metallic disc. This process clearly continues as long as there is electricity to attract the balls.

The balls are often projected too far from the suspended disc to be attracted again. To prevent this the disc and balls are often enclosed within a cylindrical vessel of glass, but even in this form

the experiment comes soon to an end because the balls adhere to the sides of the glass. Small elongated pieces of pith with blunt points, of the shape and size given in fig. 320, *A*, or pieces of paper cut like fig. 320, *B*, are less liable to be thrown about than common pith-balls. Bodies of this shape dance pretty long between disc and table, without requiring a glass cylinder to keep them from flying sideways. The pieces of paper sometimes lie motionless at first upon the table, but begin to dance when they are a little raised.

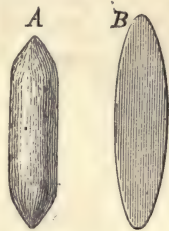


Fig. 320 (*real size*).

If the cover of the electrophorus is simply charged in the usual way, by placing it upon the cake, touching it with the finger and then raising it, it will without the help of the electrical machine cause the balls to dance if held a few centimetres above them. This will of course only last for a very short time, but may be frequently repeated.

If a few pith-balls are placed upon the cover while it is still upon the cake of the electrophorus, and the cover be raised, repulsion will take place and the balls will fly off in wide arcs.

‘Electrical chimes’ may be constructed by means of two small bells, one of which, *b* in fig. 321, *A*, is in metallic connection with the conductor of the machine, while the other, *a*, communicates with the ground. Between them is suspended, by a silken thread, a small metallic clapper. When the machine is worked, *b* becomes electric, attracts the clapper and repels it again immediately after contact. Partly by this force of repulsion and partly by the force with which the unelectric bell *a* attracts the electrified clapper, it flies to the bell *a*, and gives up its electricity because *a* communicates with the ground. As soon as the clapper has thus returned to the neutral state it is again attracted by *b*, and the process is repeated as long as the machine is worked. The continued striking of the clapper produces a gentle tolling of the bells.

The small bells required for this experiment, are like those used as alarums in small clocks, and may be procured from a clockmaker or purchased at the dealers in electrical apparatus. They should, if possible, give out notes which have either the same pitch or differ by a consonant interval, one being the third or fifth of the other

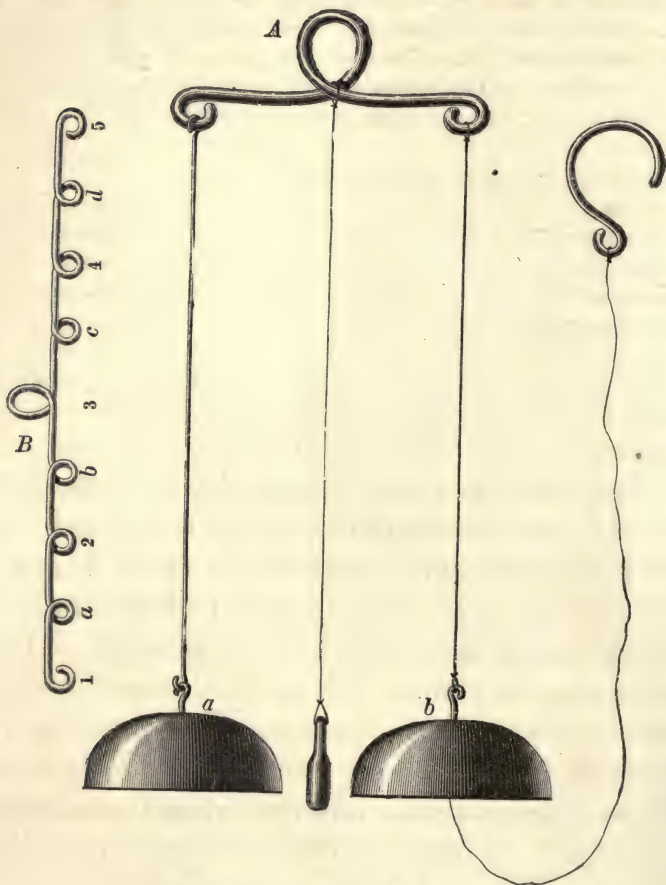


FIG. 321 (*A* $\frac{2}{3}$ real size, *B* $\frac{1}{3}$ real size).

The clapper is made of a piece of brass wire, about 3mm thick and 12 or 15mm long, which is rounded at each end with the file, and then flattened on both sides at one end, as shown in the figure. With a small drill (see page 168, fig. 118) a hole is made in the flattened part for the silk thread. Two small pieces of brass wire, 1mm thick and 3cm.5 long, are bent at one end into a ring of 4mm diameter; the

straight part is drawn through the hole in each bell, and the other ends are then bent into similar rings. To one of the lower rings a piece of silver thread (of the kind used in embroidery-work) is tied, having a length of several decimetres, and a wire hook is attached to the other end of this thread, which serves for suspending it from the stalk of the small brass ball of the conductor. A wire or small chain could not be used instead of the silver thread, because they would pull the little bell aside by their weight. The bell to which the silver thread is tied is suspended by a thread of twisted silk, and the other bell by a wire, to a cross-piece of stout wire which also carries the clapper; it is bent as shown in the figure, and clamped in the retort-stand while used.

A larger set of chimes may be made by giving to this cross-piece the form shown at *B* in the figure; clappers are suspended from *a*, *b*, *c*, and *d*; at 1, 3 and 5, bells are hung by wires, at 2 and 4 bells are suspended by silk threads, and the bells at 2 and 5 are provided with silver threads which by a joint hook are connected with the conductor of the machine.

If a small loose plug of cotton wool, about as large as a thimble, be held between the tips of the forefinger and thumb, at about 10^{cm} from the conductor, the fibres will, in consequence of electrical attraction, point towards the conductor. When the plug is let go, it flies to the conductor, becomes charged with electricity, is repelled back again to the hand, loses its charge, is then attracted again, and so on. If the hand is brought nearer to the conductor, the motion of the plug to and fro becomes so rapid that it can scarcely be distinctly seen.

The single fibres repel one other while in the electric state, hence a number of them fly off and adhere to all parts of the machine. They act like points, and must therefore be carefully looked for and wiped off before the machine is used for other experiments.

For insulating conducting bodies of somewhat large dimensions the 'insulating stool' is used; it consists of a board of hard wood, supported on glass legs covered with varnish. The experimenter, by standing upon such

a stool and placing the outstretched hand on the conductor, or holding in his hand one end of a chain of which the other end is suspended from the conductor, may charge his own body with electricity, if the machine is worked by an assistant. Sparks may be drawn from the person on the stand by others, or he may draw sparks from his own body by bringing his finger or a small metal rod, held in the hand, near conducting bodies. The electrified human body manifests phenomena of repulsion and attraction like other electrified bodies; for example, if the hair of the person standing on the stool is pretty dry, it will more or less completely stand on end, in consequence of mutual repulsion of different hairs.

The glass legs of the insulating stool must, of course, be dry; if necessary, they must be dried by friction and warmth. The stool should not be too near the table upon which the machine is placed, that there may be less probability of contact between the table and the clothes of the person standing on the stool. Nor must his clothes, for obvious reasons, touch those of any person near him.

The dissipation of electricity through the fibres of the clothes, the hairs, and other projecting points, is so considerable that not much electricity can be accumulated in the human body. The sparks drawn are never large.

An insulating stool need not be specially purchased. It can easily be put together by placing a board, a few decimetres long and wide, upon four strong inverted tumblers, which serve as legs. If the tumblers have not all the same height, a few pieces of cardboard or folded paper, used to fill up any space between tumbler and board, will easily enable the experimenter to stand securely upon the improvised stool, provided that a little caution is used in mounting upon the stool. The tumblers can bear a great load, but the experimenter should at once step gently on to the centre of the board, so as not to push sideways against the tumblers, which might break them.

No varnishing is recommended when the tumblers are to be used only temporarily, as the varnish cannot be removed without inconvenience and a rather considerable expenditure of spirit of wine. If it should be found that the insulation is imperfect, their surface

should be rubbed over with a little tallow ; a thin covering of tallow prevents the formation of a conducting layer on the surface of the glass very well, and can be simply wiped off again afterwards.

47. *Condensers of Electricity. Effects of electrical discharge.*—The tendency which electricity has to escape from bodies, its tension, assigns a limit to the quantity of electricity which may be accumulated in a conductor of

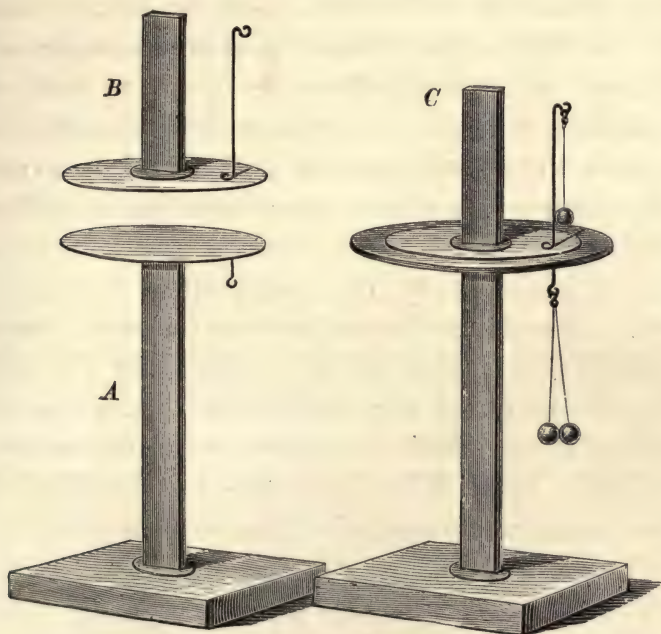


FIG. 322 (an proj. $\frac{1}{3}$ real size).

a definite size. A conductor of a given magnitude of surface can only hold a certain quantity of electricity, which becomes less the greater the number of projecting points, corners, and sharp edges which the surface of the conductor contains. A small disc of thin metal insulated on a stick of sealing-wax, like that at *A* in fig. 322, gives but very small sparks, whether it is elec-

trified by drawing a rubbed glass rod once or several times along it, or by connecting it with the conductor of the machine. Whatever is added beyond the quantity which the disc can hold is dissipated by its edge; even the wire attached to the lower surface tends to increase this dispersion.

If a second similar disc, also provided with an insulating handle of sealing-wax, *B* in fig. 322, be placed upon the first, so that their surfaces are in perfect contact, and an electrical charge be given to both, the sparks are not sensibly larger than those obtained from one disc. The joint surface of both discs is not appreciably greater than that of one; hence the quantity of electricity which can be accumulated in both is not sensibly increased by the superposition of the two discs. In order to investigate the electrical state of either disc, let a pith ball be suspended by a linen or cotton thread to the wire fixed in the upper disc, and two similar pendulums to the lower disc, as indicated at *C* in fig. 322. When both discs are electrified, the upper pendulum is repelled by the wire from which it is suspended, while the two pendulums below repel each other. The divergence of the pendulums caused by drawing the rubbed glass rod once along the discs is not increased by drawing it several times along them; it follows that repeated electrical excitation does not increase the quantity of electricity which the discs retain.

Now let a thin disc of some insulating substance, such as ebonite, glass, or sealing-wax, having its diameter about 2^{cm} greater than that of the metal discs (as seen in fig. 322, *C*), be placed between them, and let

the upper disc be charged by drawing a rubbed glass rod along the wire fixed upon it. The charge received will not be sensibly greater than it was before introducing the insulating disc. Very different results will, however, be obtained, if

First, the lower disc is connected with the table and thus with the ground by means of a wire about 15^{cm} long, one end of which is bent into a hook which is attached to the wire fixed in the lower disc. When electricity is now communicated to the upper disc, the pendulum rises but slowly, and the rubbed glass rod must be drawn repeatedly along the wire on the disc, that the divergence of the pendulum may be the same as it was in the first experiments. The upper disc having been charged in this manner, let the thumb be placed on the lower disc and the forefinger be brought near the upper disc: a spark will pass between the upper disc and the finger; it is not longer than the sparks drawn in the first experiments, but is brighter, louder, and can be much more distinctly felt. While the previous sparks were hardly perceptible to the feeling, a smart shock is now felt in the joints of the fingers.

Second, the apparatus being charged exactly as in the preceding experiment, the wire which connects the lower disc with the table is removed, the upper disc is lifted by its handle of sealing-wax, and the insulating disc is also taken down, care being taken to touch neither of the metallic discs with the finger. On testing the lower disc by means of a charged electroscope it will be found to be *negatively* electrified, if, as has been supposed in the experiment, the upper disc was charged *positively*.

Third, the apparatus is again arranged as at *C* in fig. 322, without discharging the lower disc, and positive electricity is communicated to the upper disc while a proof-plane is kept in contact with the lower disc. When the electricity of the proof-plane is tested it is found to be *positive*.

The electricity communicated to the upper disc effects a separation of the two electricities of the lower disc. The electricity of the same kind—in our experiments positive—is repelled, and passes in the first experiment into the ground, in the last experiment into the proof-plane. The electricity of the opposite kind—in our case negative—is bound by the electricity of the upper disc, but when first the conducting wire and then the upper disc and the insulating plate are removed, this electricity becomes free and may be tested by the electroscope. The two electricities, viz., that communicated to the upper disc and that of opposite kind induced by it in the lower disc, exert mutual attraction, but are prevented from uniting by the intervening insulating layer. Their mutual attraction overcomes the tendency which they have to escape, that is, their tension, and under the circumstances of these experiments it becomes thus possible to accumulate much more electricity within a given small space than could be done without taking advantage of the attraction which one kind of electricity exerts upon the opposite kind.

That each of the two electricities is really bound may be proved by charging the upper disc as in the first experiment and afterwards removing the conducting wire. If now first the upper and then the lower

disc are *alternately* touched with the finger, a small spark will be drawn each time when one of the discs is touched, and when, after repeating this several times, thumb and finger are used as in the first experiment for discharging the apparatus, a smart shock will still be felt. This proves that when each plate was touched separately by a conductor, only a very small quantity of electricity could really have been removed.

If the two electricities of the discs were to bind each other completely, it would not be possible to withdraw any electricity from them when they are touched by the finger one at a time. But the two electricities cannot bind each other completely, inasmuch as they are separated by a sensible distance, which in this case is equal to the thickness of the intervening insulator. A given quantity of electricity can, at any distance, only bind a quantity of the opposite electricity less than itself, and if of two electricities at some distance from one another, one is completely bound, there must be a certain surplus of the other. When the upper disc is charged while the lower communicates with the ground, the induced electricity of the lower disc is completely bound by the original charge, while a free surplus of the latter exists in the upper disc. This free portion manifests itself by the divergence of the upper pendulum; the lower pendulums hang down because there is no free electricity in the lower disc which could cause them to diverge. When the conducting wire is removed, and the upper disc touched by the finger, the upper pendulum drops. But now the lower pendulums diverge; for the quantity of electricity in the upper disc being diminished, because the free portion has been removed, it can no

longer bind the same quantity as before in the lower disc, hence a portion of the electricity in the lower disc becomes free, and causes a divergence of the pendulums. There must now clearly be a surplus of negative electricity in the lower disc, for when the upper disc was touched only that quantity of positive electricity was left behind which the negative electricity on the lower disc was capable of binding, that is, a less quantity of positive electricity was left in the upper disc than of negative electricity in the lower disc. When the surplus of negative electricity in the lower disc is again conducted away through the finger, the lower pendulums drop and the upper pendulum rises; there is now free electricity in the upper disc, because the quantity in the lower has been diminished. By alternately repeating the operation, the apparatus may be completely discharged; each time the surplus of free electricity in one disc is taken away, and thereby a quantity of electricity set free in the other disc.

The process may be illustrated numerically if, for example, we suppose the distance between the two discs to be such that a given quantity of positive electricity communicated to the upper disc, which we may represent by the number 1,000, can only bind $\frac{19}{20}$ of this quantity of the opposite electricity in the lower disc. Then we should have, at starting, 1,000 of positive electricity in the upper disc, and $\frac{19}{20} \times 1,000 = 950$ of negative electricity in the lower disc. This 950 can only bind $\frac{19}{20} \times 950 = 902.5$ of positive electricity in the upper disc, in which there is therefore $1,000 - 902.5 = 97.5$ of positive electricity in the free state. This 97.5 of positive electricity is removed when the upper plate is touched, and the remaining 902.5 now binds only $\frac{19}{20} \times 902.5 = 857.375$ of negative electricity in the lower disc, so that $950 - 857.375 = 92.625$ is in the free state. This calculation may be continued in the form of the following small table.

After	UPPER DISC			LOWER DISC		
	Total Quantity	Bound	Free	Total Quantity	Bound	Free
Charging	1000	$\frac{19}{20} \times 950 = 902.5$	$1000 - 902.5 = 97.5$	950	$\frac{19}{20} \times 1000 = 950$	0
1st touching (above)	902.5	902.5	0	950	$\frac{19}{20} \times 902.5 = 857.375$	$950 - 857.375 = 92.625$
2nd touching (below)	902.5	$\frac{19}{20} \times 857.375 = 814.506$	$902.5 - 814.506 = 87.994$	857.375	857.375	0
3rd touching (above)	814.506	814.506	0	857.375	$\frac{19}{20} \times 814.506 = 773.781$	$857.375 - 773.781 = 83.594$
4th touching (below)	814.506	$\frac{19}{20} \times 773.781 = 735.092$	$814.506 - 735.092 = 79.414$	773.781	773.781	0

and so on.

The instantaneous discharge of the apparatus is only possible if both discs are connected by means of a good conductor, as for example when both discs are touched simultaneously by different fingers of the same hand, or by placing one hand upon the upper disc and the other upon the lower. In that case the discharge is quite sudden and instantaneous. On the contrary, if the connection between the two discs is made wholly or in part by a less good conductor, the discharge takes place more slowly and is less perceptible to the touch. Such a slow discharge may be brought about by connecting the lower disc by a wire with the table and bringing the finger near the upper disc without touching the lower. The discharge is retarded in this case, because the two electricities in order to unite have not only to pass through the wire and the human body, both good conductors, but also through the table and the floor, which are much worse conductors.

Apparatus like the one described, which serve for condensing a large quantity of electricity on a comparatively small surface, and which consist essentially of two

insulated conductors separated by a non-conductor which projects beyond the conductors, are called *condensers* or *accumulators*.

The two discs are cut out of sheet brass or zinc, 7 or 8^{cm} in diameter; any rough edges produced in the cutting must be filed very smooth, and each disc must be hammered quite flat with the mallet; if brass is used, the discs must first be softened over a lamp or a small charcoal fire. A wire, previously bent as shown in the figure, is soldered to each disc. After washing off the soldering liquid and drying them, the discs are heated until a stick of sealing-wax melts when pressed upon them. The stick of wax which carries the lower disc is fixed at the lower end to a small board which serves as foot. The pendulums are not tied to the wires which are attached to the discs but to small wire hooks, which can be more easily hung into the eyes bent at the ends of the wires and can be conveniently removed again. This mode of suspending the pendulums is the more advisable as in several experiments they are not required; and as they cause by the fibres of the threads a dissipation of electricity which diminishes the quantity in the apparatus, the pendulums should only be suspended when the existence of free electricity is to be rendered manifest.

As insulator, a glass plate is best; if there should be difficulty in obtaining glass which insulates well, a plate of ebonite or sealing-wax must be substituted. Ebonite, especially when dried before the experiments, is a very good insulator and is not easily broken, but is more expensive than sealing-wax. The thickness of the plate, of whatever material it may consist, should not exceed 2^{mm}; the diameter must be at least 2^{cm} greater than that of the discs, that is about 9 or 10^{cm}; it may be greater but not smaller, for in that case union of the two electricities takes place across the edge of the insulator.

To cast a plate of sealing-wax, 50 or 60 grammes are melted at a very moderate heat in a very small earthen pot or in an old china cup, and the melted mass is poured upon an even surface, when another flat surface is pressed upon it. Two glass plates, or wooden boards which have each been made quite flat with the plane on one side and then covered with tinfoil, will serve for the purpose. The flat surfaces of the plates or boards must be covered with a thin layer of fat, to prevent the sealing-wax from adhering. They are rubbed over with an end of a tallow candle or wiped with a piece of cloth dipped in oil. When the sealing-wax is quite cool, it is removed by pressing sideways against the plates and the wax, for their adhesion

is so great, in consequence of the layer of fat, that they cannot be separated otherwise.

The vessel in which the sealing-wax has been melted may be cleaned by boiling in it a little of a strong aqueous solution of soda, which dissolves the sealing-wax.

The plate of sealing-wax is exceedingly brittle, and must therefore be handled with great care; it should not be preserved by keeping it between the discs, but upon some support, with a sufficiently large, flat surface, as otherwise it would become bent in the summer. The support should be slightly greased to prevent the plate from adhering.

Before using the plate the adhering fat or oil should, for the sake of cleanliness, be carefully wiped off, although its presence would by no means interfere with the experiments, since oil and fat are good insulators.

If a condenser is only to be used for accumulating large quantities of electricities, the two conductors may be firmly connected with the insulator, since the necessity for separating the essential parts from each other arises only when the mode of action is to be investigated by means of the electroscope.

A very simple form of the condenser, called 'Franklin's plate,' resembles very much the apparatus just described. It consists of a rectangular or sometimes round plate of glass, on each side of which pieces of tin-foil are fastened opposite to each other, leaving a space of a few centimetres free all round the edge.

A Franklin's plate or pane may be easily constructed by having a plate of well insulating glass cut by a glazier so as to fit into the wooden frame of a common slate, as used by school children, the slate being taken out. Pieces of tin-foil are pasted upon both sides; they should everywhere be about 2^{cm} from the wooden frame. It is well to cover the intermediate portions with an insulating layer of shellac varnish. Into the middle of one edge of the frame a short piece of stout wire is driven, leaving a portion to project, which is bent into a ring for attaching a chain by which communication may be established with the ground. The ring is connected with one of the

metallic coatings by a narrow strip of tinfoil which is pasted on the glass. To charge the plate the insulated metallic side is connected with the machine, and if the other side communicates with the ground, the two coatings act exactly like the two discs in the apparatus previously used. If connection between the two coatings be made by touching them with the hands a violent shock is felt.

✓ The *Leyden jar* (fig. 323) is a condenser which differs from Franklin's plate only in its shape, the coatings and the insulating plate being not flat but rolled up in the form of a jar. A metal rod, which ends outside in a knob and communicates within the jar with the interior coating of tinfoil, serves for charging the interior with electricity.

If the student does not possess an electrical machine, and is confined to the glass rod and the electrophorus as his sources of electricity, two Leyden jars are quite sufficient, one 5 or 6^{cm} wide and from 7 to 9^{cm} high, the other 8 or 10^{cm} wide and 12 or 16^{cm} high. For use with the machine, one or several (from two to four) larger jars are desirable, about 15 or 20^{cm} wide and from 24 to 32^{cm} high.

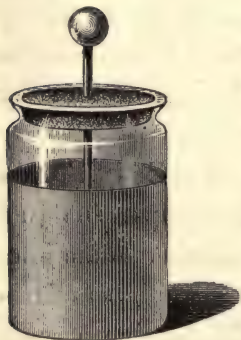


FIG. 323
(an. proj. $\frac{1}{3}$ real size).¹

Bottles of hard glass with very wide necks, such as common pickle bottles, are the most convenient for attaching the inner coating. Such bottles of white glass may be purchased at the dealer's; the common pickle bottles are mostly of green glass, which does not look so well, but serves the purpose quite as satisfactorily.

Before coating the jar its insulating quality should be tested. The jar is rubbed with a dry cloth, especially the upper part, and a piece of silvered paper, broad enough to cover about two-thirds of the height of the jar and so long as to pass amply round it, is wrapped firmly round the jar, leaving an edge beyond the bottom about 1^{cm} wide. The paper is tied to the jar with thread, and the projecting edge is bent in so as to be everywhere close to the bottom of the vessel. Iron filings are then thrown into the vessel until it is about two-thirds filled with them. The vessel now represents a temporary Leyden jar with two coatings, and a metal

rod with a knob, which has been prepared previously, is stuck into the middle of the filings so as to stand upright. The apparatus is then charged by the electrophorus or the machine in the manner given farther on. If no satisfactory result is obtained another jar is tried, until one is found which acts well. This is now provided with the proper coatings, after removing the filings and the paper.

The rod is made of brass wire, 3 or 4^{mm} thick (for larger jars about 6^{mm}), and about one-third longer than the height of the jar. A leaden bullet does not make a very suitable knob, as it is difficult to give it a perfectly smooth surface. It is better to use a brass knob like those mentioned previously (see page 604), of 12 or 15^{mm} diameter, or about 20^{mm} for very large jars. As these knobs are generally provided with screws soldered to their inside, they should be held by the crucible tongs in the spirit-flame; the solder melts and the screw will fall out. There is generally sufficient solder left for attaching the metal rod; the end of it is dipped into soldering liquid and pressed inside the knob, which is held in the flame. If necessary a little soft solder must be added. The lower edge of the knob, which is usually rather rough, should be smoothed with the file; this is best done after fixing the metal rod, which serves for holding the knob during the operation; it is somewhat difficult to file the edge smooth while holding the button by itself in the hand, nor can it be clamped between the jaws of a vice without running danger of crushing it out of shape or breaking it.

Instead of leaving the knob hollow it may be filled with lead. The end of the rod is first covered with a little soft solder; the knob is then held in the flame with its opening upwards, and small bits of lead are thrown into it until it is full of molten lead; the rod is now seized with the flat pliers, the end covered with soldering fluid and dipped into the lead. The pliers must be used because the metal rod is too hot to be held in the hand after its end has been a short time in the molten lead. The rod must be held upright until the lead has become solid. The small quantity of lead pushed out by the rod is first cut off with a knife, and then the whole smoothed, using successively the rasp, the smooth file, and emery paper.

Solid brass balls with iron or brass stalks attached to them may be obtained at the ironmonger's, and with a little trouble they may be prepared so as to form knobs which look much better than the kind just described. Besides knobs such as that represented in fig. 324, A, there is another kind also sold under the name 'stoll-balls,'

which are solid, or at least not open around the screw. From one of these knobs or from a solid ball with a stalk, a suitable knob is made by filing the screw or stalk into a flat short piece, $1\text{mm}\cdot5$ thick and 1cm long, which is done by clamping it horizontally in the jaws of the vice so as to project above the cheek to nearly the middle, taking care to present the 'safe' (uncut) edge of the file used for the purpose to the ball, and thus avoid scratching it. When one side is filed flat it is turned downwards and the other side is then flattened. If a stool-ball with a screw is used, the projecting portions of the worm must also be filed off the sides. The rod to which the knob is to be fixed is then clamped upright in the vice, and a cut is made in it



FIG. 324.

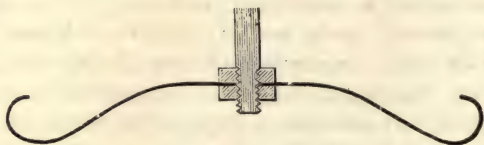


FIG. 325.

with a metal saw. The flat stalk left on the ball is filed until it fits into this cut and is then fixed into it by solder. Fig. 324, *B*, shows the end of the rod and the ball before they are fixed together.

A screw 1cm long is cut at the lower end of the metal rod and two small square nuts are prepared for it. Between the two nuts is clamped an elastic strip of brass, 6 or 10mm wide, with a hole in the middle, and bent as shown in fig. 325. The length of the strip should be such that the distance between the two bent extremities is somewhat greater than the width of the jar for which it is used. The strip is made elastic by hammering; sheet brass, $0\text{mm}\cdot5$ thick, is taken and the thickness reduced to about $0\text{mm}\cdot3$, which gives sufficient elasticity.

The tinfoil is first attached to the inside. Strips are cut, 4cm or 6cm wide (for large jars 8cm or 12cm), and long enough to reach from where the coating begins to the bottom of the jar and to leave still about 1cm for the bottom itself. A layer of starch-paste being brushed over one of the strips, it is placed inside in the proper position and fixed by pressure and rubbing with the finger at the top;

where the upper edge of the coating is to be. The upper portion being kept firm by placing the thumb of the left hand outside upon the jar and opposite to it the first and second fingers inside upon the tinfoil, so as to prevent its being again displaced, the lower part is fixed by applying pressure from above downwards. Small jars will only allow of the forefinger being placed inside. The free use of the right hand for the operation of pressing and rubbing will only be possible in very large jars; usually a small stick of wood of the size of a pencil will have to be used, to the end of which a small piece of linen or cotton stuff is tied with thread so as to form a roundish plug. When the strip is fixed well to the side of the jar, the last portion is pressed upon the bottom, being careful to rub and press at first gently, or the upper portion of the strip might be torn off again; after a little while greater pressure may be used. When the first strip is fixed a second is introduced and attached in the same manner, but, to prevent paste being squeezed underneath the first strip, pressure and rubbing should only be applied downwards, not from side to side. The second strip should overlap the first 3 or 4^{mm} along the side, and its upper edge must be carefully placed in the same horizontal line. The other strips are proceeded with in like manner until the inner coating for the sides is complete. A circular disc of tinfoil, being about 5 or 10^{mm} narrower than the vessel, is then fixed to the bottom. It is necessary to make an incision in the disc from the edge to the middle, so that the disc may better adapt itself to the form of the bottom; the cut edges may overlap one another afterwards. The outer coating is attached in the same manner. The paste should be neatly removed where visible with a moist rag, the whole carefully dried, and the free portions of the glass covered with shellac varnish. The glass should be heated cautiously for the varnishing, as the upper portion of the tinfoil when it gets too hot is apt to blister.

The rod is fixed in small jars by means of a bung cork; for larger jars a disc of thick pasteboard may be used. The cork or the pasteboard disc should fit very tight into the neck of the jar, and the hole in the middle for receiving the metal rod should only be just large enough for the purpose. The cork or disc is pushed from below upwards to near the knob, the elastic strip of brass is then fastened to the rod, and pressing the brass spring a little together, that it may pass through the neck, the rod is made to touch the bottom of the jar, and the cork pushed down and pressed into the neck so that the top of it is flush with the rim of the jar. Cork or disc is further secured with sealing-wax, by placing first a thin layer all round and then cautiously melting it uniformly with the blowpipe,

as shown in fig. 121. To give a better appearance to it, the cork or disc may be covered with a coating of a solution of 12 grammes of sealing-wax in 6^{cc} of spirit of wine, made in a small corked glass bottle. About a day is required for the sealing-wax to dissolve, but frequent stirring is required during this time and also previous to using it, as it is apt to be lumpy. The coating dries very slowly; a few days elapse before it is quite hard. It is usually necessary to repeat the operation several times, but no new coating should be given unless the previous one is perfectly dry.

For very large jars two elastic brass strips, placed crosswise, will be required to secure the steady position of the rod.

The most convenient mode of charging the Leyden jar is to place the left hand round the lower portion of the outer coating, and hold the jar so that the knob is quite close to, or touches, the conductor of the machine, which is worked with the right hand. Large jars which cannot be safely held with one hand should be held with both hands, the machine being worked by an assistant; or they may be placed near to the machine upon the table, and conductor and knob joined by the discharging rod described farther on.

Jars of medium or small size may be charged from the electrophorus by sending 50 or 100 sparks from the cover into the knob. The electrophorus should for this purpose be raised on some support, so as to be only 5 or 6^{cm} below the knob of the jar; it is then not needful to lift the cover very high. The following mode is still more convenient:—The jar is held in the left hand nearly upside down (this of course cannot be done with the test jar filled with iron filings), a little slanting, the knob being about 4 or 5^{cm} above the edge of the cover of the electrophorus. The strings of the cover being held between the thumb and forefinger of the right hand, the little finger of the same hand is allowed to touch the cover while it still rests on the cake; then the thumb and forefinger are moved upwards until the cover sends a spark into the knob of the jar, the cover is then again lowered until it touches the cake, and thus by alternately touching with the little finger, and raising and lowering the two other fingers, the jar may be very conveniently charged. Care must be taken not to touch the cover with the hand while it is near to, or in contact with, the knob of the jar; in that case the jar would be discharged, and the unexpected shock might cause the experimenter to drop the jar and break it.

A very small jar may be charged by the glass rod. The jar being held between the outstretched thumb and forefinger of the left hand, the cloth with the amalgam is kept round the glass rod

by the palm and the three other fingers, the glass rod itself being so directed with the right hand that it may glide during the rubbing constantly along the knob of the jar. The metal rod which carries the knob should be a little bent if necessary to facilitate the operation.

The action of the Leyden jar is the same as that of the condensing apparatus previously described. Electricity of some kind, usually positive, is communicated to the inner coating, and effects electrical separation in the outer coating, binding the opposite, usually negative, electricity, and repelling the like, usually positive, electricity, which must be carried away, or it would exert a repulsive action upon the electricity in the inner coating, and would prevent its becoming bound, that is, condensation would be impossible. As ordinarily the jar is held in the hand or placed upon the table, provision is thus made for the outer coating being in conducting communication with the ground. In order to prove that the jar cannot be charged if the outer coating is insulated, it is placed upon the cake of the electrophorus, or upon a small insulating stool (if the electrophorus is in use), which may be constructed by placing a disc of cardboard of the size of the bottom of the jar upon three pieces of sealing-wax about 3^{cm} high. When the jar is insulated, and electricity is communicated to the inner coating, the free induced electricity in the outer coating may be rendered manifest by placing the finger or another conductor near it. If the jar is charged from an electrophorus, sparks will be seen to pass, when the distance between the coating and the conductor is not more than 2^{mm}; if it is charged from the machine the distance may amount to 1 or 1^{cm}.5.

When a charged jar is held in one hand, and a finger

of the other hand is quickly brought near the knob, it is discharged; a spark appears which is rather small but loud and bright, and a smart shock is felt, especially in the joints. In a small jar, charged by a glass rod or the electrophorus, the length of the spark is from 5 to 8^{mm}. With the machine, jars of well insulating glass, having a thickness of 3^{mm}, may be charged so strongly as to give sparks from 3 to 6^{cm} long; it sometimes happens under these circumstances that a spark passes from one coating to the other across the insulating portion of the glass. With equal charges, a jar of thin glass gives shorter sparks than one of thicker glass, because in the former case the two electricities are nearer to one another; the mutual attraction is therefore greater and they consequently retain less tension. When the glass is too thin a spontaneous discharge takes place through the glass in consequence of the increased mutual attraction of the two electricities, and the fracture caused by the passage makes the jar useless, for if charged the electricity passes at once through the hole in the glass from the inner coating to the outer.

For discharging jars without undergoing the electric shock a 'discharger' is used, represented in fig. 326. It consists of a stout bent wire terminating in knobs and attached to an insulating handle.

A brass wire, from 25 to 40^{cm} long and 2^{mm} thick, is softened in the flame, and brass balls, of the kind previously described, which may be left hollow, for the sake of lightness, are soldered to the ends. In the middle the wire is bent into the form shown in dotted lines in fig. 326; this portion is to be fixed into a brass cylinder. A piece of glass, from 12 to 20^{cm} long, is broken from a larger rod by first making a deep cut all round with the tri-

angular file, moistening the file with water or paraffin oil, and then breaking the piece off. Both ends are somewhat rounded off on the grindstone. A rectangular piece of sheet brass, 0mm·5 thick, is softened in the flame, and hammered upon a round piece of wood or metal into a cylinder wide enough for the glass handle to fit into it easily. The edges of the cylinder should overlap at the joint about 2mm. The joint is brushed over with soldering liquid; a small piece of soft solder is placed upon it and heated over the spirit-flame until the solder has well filled the whole length of the joint. About half of the inside of the cylinder is then brushed over with soldering liquid, and the same is done with the bent middle portion of the wire, which is placed into the cylinder; a piece of solder about the size of a pea is laid inside upon the wire, and heat is applied until the solder has run everywhere between the wire and the side of the cylinder, which must be a little turned about for the purpose. The residue of the liquid must be washed carefully away. To remove it from the inside a goose-quill should be used, and any solder which has run upon the outside should be filed away neatly. The cylinder being moderately heated, the inner side next receives a coating of sealing-wax; when this is cold, the end of the glass handle is heated to the melting point of sealing-wax and pushed into the cylinder.

The two arms of the discharger are finally bent into the form given in the figure; they may of course be bent farther apart or brought nearer whenever required.

In using the discharger it is held by the glass handle, one knob is placed upon the external coating, and the discharger so turned that the second knob can be rapidly brought near the knob of the jar. A gentle

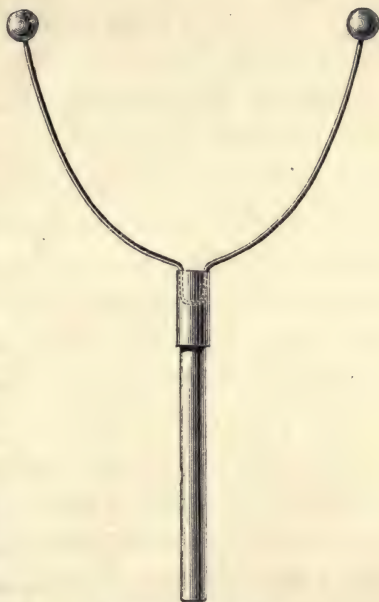


FIG. 326 ($\frac{1}{4}$ real size).

pressure must be applied to the knob which is in contact with the external coating to prevent its gliding off, in which case the discharge might pass through the body of the experimenter.

During the discharge of the Leyden jar, one electricity passes through the conductor which connects the two coatings from the inner coating to the outer; the other electricity passes at the same time from the outer coating to the inner, and a recombination of the two electricities takes place within the conductor. This motion of the two electricities, which constitutes the electrical discharge, has also been termed the 'discharge current.'

The effects of the discharge are of various kinds. Besides the luminous effects in the spark, and those upon our nervous system in the shock, the discharge produces mechanical effects, such as violent movements, fractures, and perforations, and is also a source of heat. Both kinds of effects are considerably heightened if the discharge takes place through badly conducting substances. The well-conducting metal parts of the jar and the discharger prevent any violent action; they are heated, but so slightly that it escapes observation. But when the discharge takes place through a bad conductor the latter may become so strongly heated as to take fire.

Among solid bodies, one which is most easily inflamed by the electric spark, is a mixture of equal portions of sulphide of antimony and potassic chlorate, very finely powdered. The mixture is placed in a small apparatus, usually termed 'the electric mortar,' shown in section in fig. 327, made of wood, with a cavity into which two wires project, their ends being

1^{mm} apart. The outer ends of the wires are bent into rings. The cavity being filled with the mixture, one end of a small chain is suspended to the left ring and the other end is held in contact with the outer coating of the jar, the knob of which is rapidly brought near to the ring on the right-hand side. At the instant when the spark passes between the ring and the knob, and between the two wire points in the mixture, the latter is ignited, the combustion taking place with almost as great rapidity as that of gunpowder.

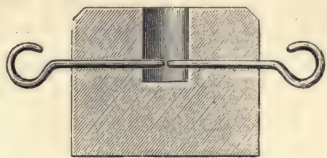


FIG. 327 ($\frac{1}{2}$ real size).

Into a small block of wood, 5^{cm} long and wide and 4^{cm} high, a hole is bored 2^{cm} deep with a centre-bit 12^{mm} wide; 15^{mm} below the top of the block a hole is bored horizontally right through the block with a fine gimlet. Wires of the form shown in the figure, and stout enough to fit tight into the holes and to sit firmly, are pushed in from either side. The ends of the wires are previously filed round.

The easy inflammability of the mixture depends entirely on the fact that both ingredients have been reduced to a very fine powder, and on account of its being so inflammable not more of it should be prepared than is required each time; for two experiments, 2 grammes of each substance is sufficient. Potassic chlorate is a white salt, sold in the form of flat crystals or a rough powder; it is not inflammable by itself, but mixed with other inflammable substances it is apt to cause dangerous combustions and explosions; it should therefore be kept in a stoppered glass bottle to keep out impurities such as dust, splinters of wood, etc. The quantity required is weighed out and ground in a very clean porcelain mortar until it feels like fine flour, not in the least gritty. The powder is then in the meantime placed on a piece of paper, and the mortar and pestle carefully cleaned and dried. The sulphide of antimony is a native ore of antimony. It is sold as a dark grey crystalline powder (called crude antimony), but not sufficiently fine for our purpose; it should therefore also be rubbed down in a mortar until it is like fine flour, and no longer shows lustrous points. The potassic chlorate is now

added to the powder in the mortar, and intimately mixed by constant stirring with the soft tip of the finger. The hard pestle must on no account be used for this operation, as combustion might take place and the hand be severely burnt.

The cavity is filled loosely with the mixture up to 2 or 3^{mm} above the wires. The cavity must not be closed by a plug, or the block will burst. The burning mass shoots upwards as a vivid jet of fire; the discharge should therefore be made with the outstretched arms, lest anything should fly into the face of the experimenter. After the experiment, the cavity should be well scraped with an old knife to remove any residue of the combustible mass.

Of liquids, ether is most easily ignited by the electric discharge; it evaporates as quickly and is as inflammable as disulphide of carbon, but has not the unpleasant smell of the latter. The handle of the flat vessel represented in fig. 328 is clamped in the retort-stand; a small chain is suspended by the ring at the end of the handle, a few drops of ether are poured into the shallow dish, the free end of the chain is placed in contact with the outer coating, and the knob quickly brought close to the raised portion in the middle of the dish; a spark will pass, which is pretty certain to set fire to the ether.

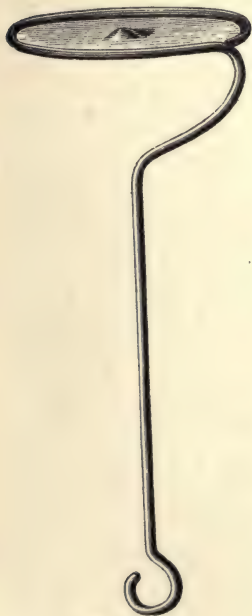


FIG. 328
(*an. proj. real size*).

The dish consists of a disc of thin sheet-brass soldered to the lower side of a ring made of brass wire, 2^{mm} thick, which forms the side of the vessel and is continued into a handle. The elevation in the middle of the vessel is made before the disc is soldered on; the disc is softened in the flame, laid upon a support of lead, a piece of iron or brass, which has been filed round at one end, is placed in the centre, and a depression is made by a very moderate blow of the

hammer. It will be more easy to solder the ring to the disc if the latter is first cut square; it may then be conveniently heated by being held at one corner with the flat pliers. When the ring is fixed on, the projecting portions of the disc may be removed with the shears and the file.

The small elevation in the middle is necessary in order to assign a definite path along which the spark has to pass; otherwise the spark spreads itself in a radiating manner over the surface of the liquid, and its heating effect is then obviously less than when it forms a single straight line. If the vessel were deep it would be very difficult to ignite the ether. The reason is that the vapour of ether formed at the temperature of the room is heavier than air, as may be proved by holding the dish, filled with ether, against the light of the window, and looking along the sides of the vessel, when the heavy vapour of ether will be seen to flow downwards over the sides. A deeper vessel, in which there is some ether, is thus quickly filled with its vapour, which forms a layer above the liquid, and when the knob is brought close to the liquid the spark passes entirely within the vapour of ether, where there is no air; hence no combustion can take place, since the free access of the oxygen of the air is an absolute necessity for combustion.

The ether is poured into the dish after the jar is charged, or the liquid would all evaporate while the jar is being charged, especially if this is done with the electrophorus. If an electrical machine is used, the jar is really not required for this experiment; the vessel is placed near the conductor, a chain is hung to the ring which reaches to the ground, one knob of the discharger is placed upon the conductor of the machine, and the other knob is held 1 or 1^{cm}.5 above the elevation in the middle of the dish.

Ether cannot be preserved under water like carbon disulphide; it is lighter than water, and mixes with it gradually when in contact with it. It should be preserved in a glass bottle closed with a well-fitting soft cork, and the bottle should always be closed and placed aside before the quantity in the dish is inflamed. If a little of the burning ether should flow over the edge of the vessel and upon the retort-stand, it may be blown out by a vigorous blow or rather a strong puff, provided that not too much ether has been unnecessarily used.

Combustible gases may be ignited even by a weak electric spark. A jet of illuminating gas issuing from a Bunsen burner may very frequently be inflamed by

bringing the charged cover of the electrophorus near to it, especially if the burner be held horizontally or nearly so. To render the ignition of a gas by a weak spark more certain, the small contrivance represented in fig. 329 may be used. It consists of a cork which carries a jet-tube and two insulated wires, between which the spark passes. The cork is clamped in the retort-stand, the jet-tube being connected by an india-rubber tube with a gaspipe or the generating apparatus for hydrogen. By means of a pinchcock placed upon the india-rubber tube the quantity of gas which issues is so regulated that the flame is not larger than indicated in the figure. Placing one hand on the ring of the left wire, and bringing the charged cover of the electrophorus near to the ring on the right, the gas is inflamed each time with certainty.

The upper ends of the two wires are at first left quite straight. The wires are heated about the middle until sealing-wax melts upon them, and then surrounded by a cylinder of sealing-wax of about the thickness of a pencil. When cold they are pushed into holes suitably bored in the cork, and are bent above into the required shape, and then the jet-tube is set in its place; the opening at the point of the jet-tube should be from 0.5 to 1^{mm} wide. Wires and tube must fit tight in their holes so as to remain firmly fixed. The distance between the ends of the wires, which should be filed round, is 3^{mm}; their height above the end of the jet-tube 1^{mm}.5. When hydrogen is used its purity must first be examined in the manner explained on page 380 before lighting it by the electric spark.

That even good conductors are heated by the electric discharge may be shown by the apparatus fig. 330. A small wide-necked glass bottle is closed by a cork, through which two wires pass and also a glass tube, which is drawn to a point, about 1^{mm}.5 wide, and bent horizontal; the wires are connected by a long, very narrow

strip of tinfoil. The glass being very slightly warmed by holding it in the hand for a moment, a drop of water is brought upon the point of the tube. The air in the bottle has expanded by the heat of the hand, and when it contracts again the drop of water passes a short distance into the tube. The external coating of a pretty

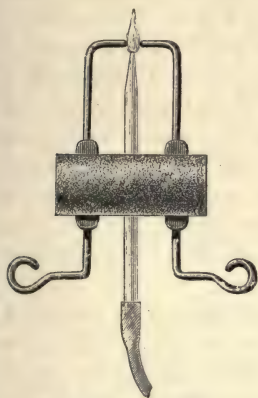
FIG. 329 ($\frac{1}{2}$ real size).

FIG. 330 (real size).

strongly charged jar is connected by a chain with the ring of one of the wires, and the knob is brought quickly near the ring of the other wire; the heat produced by the passage of the spark through the strip of tinfoil is sufficient to expand the air in the bottle again, and the drop of water is pushed outwards by the expanding air through a space of one or several millimetres.

The wires in the apparatus, fig. 330, pass immediately through the cork; they need not be insulated, for cork is by no means a good conductor, and as in this experiment the charge must be pretty strong, only a comparatively insignificant quantity passes through the cork, while the much greater portion passes through the tinfoil, which is by far the better conductor. The strip of tinfoil should not be more than 0^{mm}·3 wide, it must be cut upon a support of sheet metal, using a ruler and a very sharp knife, of which, if possible, the cutting edge should end like that of a razor, that is, it should

be slightly curved, not pointed. The ends of the strip are attached to the wires by pasting round strip and wire another strip of tin-foil, 5^{mm} wide and 10^{mm} long.

While by means of a single jar the heating effect of the discharge can only be just rendered visible, a powerful discharge is capable of fusing, and even igniting, the strip of tin-foil. For this purpose several jars must be joined together; they then form a so-called *electric battery*. It usually consists of four or more jars, pretty large and of nearly the same size, whose internal and external coatings are respectively connected with each other. The external coatings are usually connected by placing the jars upon a common conducting surface, for example, a sheet of cardboard or a wooden board covered with tin-foil, or by placing them in a shallow wooden box lined with tin-foil. The internal coatings are connected together either by metallic rods, which are inserted into holes made for the purpose in the knobs of the jars, or more simply by passing a moderately stretched metallic chain round the metal rods of the jars; the end of the chain may be used at the same time for connecting the battery with the conductor of the machine.

For many experiments with the electric battery a so-called *universal discharger* (*Henley's*) is almost indispensable. It consists of a wooden stand which carries two short insulating pillars, each provided with a joint in which moveable metal rods are fitted. Between these pillars is a small table on which the object under experiment is placed. A simple apparatus of this kind may be constructed by fixing upon a small wooden board, 8^{cm} from one another, in a line, three very stout sticks of sealing-wax, the middle one being 7^{cm} and the two outer ones 10^{cm} high. The middle stick carries a thin round board, 6^{cm} in diameter, cut out of a cigar-box; to the tops of the two outer sticks corks are fixed horizontally. Two pieces of brass wire, from 15 to 18^{cm} long and 2^{mm} thick, are softened from end to end in the flame, one end of each is bent into a ring, and the straight part is pushed horizontally through one of the corks, which are perforated for the purpose with the bradawl. By moving the wires nearer and farther from one another, and bending them suitably, their ends may be placed in any position required for each experiment.

In order to fuse a strip of tin-foil the straight ends of the wires are turned towards each other and kept 6^{cm} apart. A small strip of tin-foil is fastened between them in the manner explained previously, and one of the rings of the universal discharger being connected by a chain with the tin-foil support of the battery, a small chain is attached by one end to the other ring, and by the other

end to one arm of a common discharger. As soon as the battery is strongly charged, the knob of the other arm is quickly brought close to a knob of one of the jars, and if the experiment is successful the whole strip of tinfoil will be fused and burn with a flash of light, being converted into oxide of tin, which is seen as a white cloud between the ends of the wire. If the experiment is only partially successful the tinfoil melts only in one or two places.

Even fine iron wire may be burnt by the discharge of a battery. Of the common iron wire sold, even the thinnest sort, which has a diameter of about $0^{\text{mm}}\cdot 2$, is too thick for the experiment; but it can be made thinner by the action of nitric acid, which dissolves the iron gradually. A piece of wire, 10^{cm} long, is bent at both ends into small loops, after softening over a spirit-lamp (not over the Bunsen flame, which burns the wire) those portions of the wire only which are required for the loops; if the middle portion is heated, the nitric acid will afterwards not properly act upon it. The middle portion is placed in a mixture of 3^{cc} of nitric acid and 30^{cc} of water, contained in a small saucer, and left there until it is as thin as possible. The wire is then well washed by a jet from the washing-bottle, and suspended by the loops to the rings of the two wires of the universal discharger, the wires being for this experiment reversed in the corks so as to turn the ends with the rings towards each other. The discharge is conducted precisely as in the experiment with the tinfoil strip. The iron wire also is sometimes only burnt in separate places; but when the experiment succeeds completely the whole is burnt and converted into small fused drops of iron oxide, which fly about in numerous scintillating sparks.

Care is required in handling the acid; if a drop should get on to the clothes it should be immediately touched with solution of ammonia carbonate, which it is best to have in readiness, for as soon as the spot becomes visible it is not easy to remove it. The hands are coloured yellow by nitric acid, and the colour disappears only gradually as the destroyed skin peels off and is replaced by a new growth underneath it.

The spark which accompanies the recombination of the two electricities is nothing else than the light emitted by the particles of air through which the discharge takes place. Air is a non-conductor, and is heated so as to become luminous even by a faint discharge. If the discharge is allowed to take place in

other gases the colour of the spark is different. Thus the spark has a beautiful carmine red colour if the ends of the conductors between which the discharge takes place are completely surrounded by hydrogen. The mode of observing sparks in various gases will be explained further on; in the meantime it may be stated that to the luminous air there are in each case super-added particles of the metals or other substances between which the spark passes. This is especially the case if the discharge is very powerful, and the metals are very near to each other. The vaporised particles of these metals, although their quantity is extremely minute, give out sufficient light for observing distinctly the spectrum characteristic of each substance.

The greater the tension which electricity possesses, the greater is the distance through which the discharge can take place through the non-conducting intervening air, and the longer therefore are the sparks. But the length of the spark does not depend solely on the electrical tension, but also on the density of the intervening air. Less dense air is more easily traversed by electricity than denser air, and hence, the tension being the same, the spark is longer in rarefied air.

An imperfect barometer, in which the space above the mercury is not a perfect vacuum, is well adapted for observing the passage of electricity through very rarefied air, provided a wire is inserted at the top, through the side of the tube, for conducting the electricity. When the knob of a charged Leyden jar is brought near to the projecting end of the wire, while the external coating is connected by a chain with the mercury in the cistern, the discharge takes place through the whole

length of the mercurial column and the partial vacuum above it, even if the latter is 20^{cm} long or more. The spark in the rarefied air assumes then the form of a broad ribbon-like flash having a green colour. The colour is caused by the trace of vapour of mercury which always exists in the Toricellian vacuum.

For experiments of this kind, wires of platinum are generally passed through the sides of glass tubes and fused into them so as to be firm and air-tight, but the operation requires considerable skill. For our present purpose it is sufficient to fix an iron wire with sealing-wax into one end of a tube, which is open at both ends, so as to close it air-tight. The tube should be 1^m long and at least 4^{mm} wide; it should be taken wider if sufficient mercury is at the student's disposal. Both ends are first heated until the sharp edges are somewhat rounded off; then the tube is warmed through the whole length and air sucked through it, in order to remove moisture from the interior. An iron wire, 1 or 2^{mm} thick and 8^{cm} long, is bent at one end into a ring; the middle of the straight portion is heated until sealing-wax melts on it, and after it has become somewhat cooler it is surrounded by a layer of sealing-wax so that it forms a cylinder a little thicker than the bore of the tube. When the sealing-wax is quite cold the end of the tube is heated, and the wire with the coating of sealing-wax pushed into it, so as to close that end of the tube completely. In heating the glass-tube it should be held somewhat slanting and the open end upwards, otherwise moisture from the flame will enter the tube, which cannot be easily removed afterwards. Nor should the end be heated more than just sufficient to melt the wax; if made too hot it is apt to crack, and besides, the sealing-wax froths up into little bubbles when in contact with the over-heated glass, becomes too liquid, and runs down inside the tube along the lower portion of the iron wire, which should be left free.

The tube thus prepared is filled like a barometer, as explained previously (see page 234). The air must be swept out as completely as possible, by allowing an air-bubble, about 2^{cm} long, to run to and fro along the tube; small quantities of air will still remain behind which will render the vacuum imperfect.

The tube being filled and the open end immersed in mercury, it is fixed vertically in the retort-stand. Into another retort-stand an iron wire, 10 or 20^{cm} long, is clamped vertically, so that one end of it dips into the mercury of the cistern. To the other end, which is

bent into a ring, a chain of sufficient length is hung which is connected with the outer coating of the jar.

The passage of electricity through rarefied air may be very conveniently observed in *Geissler's tubes*. These are tubes of glass filled with air or different gases in a very rarefied condition; they are hermetically closed and therefore always ready for use. At the ends of the tube two platinum wires are fused air-tight into the glass. The tubes are usually not simply straight, but are bent into various pleasing forms; they often contain bulbous enlargements, either globular, oval, or of other shapes, the variety of form being calculated to increase the brilliancy of the electrical phenomena which they are used to exhibit. Frequently they are put together of various kinds of glass, each of which appears of a different colour when it transmits the light of an electrical discharge. Fig. IV of the coloured frontispiece shows a tube of this kind, which contains a small cup with a hollow stem of *Uranium glass*. This glass appears in daylight of a yellowish-green colour, while by the light of a lamp it is nearly quite yellow; when seen by the light of the electric spark its colour is a splendid pure green. The outer ends of the platinum wires are bent into small loops. A chain for connecting it with the outer coating of the jar is attached to one of the loops, and the knob of the charged jar is brought near the other loop quickly, but cautiously, so as not to strike against the thin-walled tube and break it.

The tubes must be clamped very gently and cautiously in the retort-stand; they are in less danger of being broken if a small wooden stand is used, shaped like a candlestick, into the cavity of which one end of the tube may be stuck. The brilliant coloured appearances which may be produced by means of these tubes cannot be adequately represented by an illustration. They are best observed during the evening in a room in which there is no other light but that of a very small lamp, just sufficient to see the apparatus which is used.

The mechanical effects of the discharge upon solid bodies may be most readily seen by placing a sheet of paper upon the external coating of a charged jar. Touching the middle of the paper with one knob of the discharger, and bringing the other knob quickly near to the knob of the jar, the paper will exhibit one or several perforations where it was in contact with the jar.

If the jar is charged by an electrophorus, a compact writing paper, not too stout, should be used; good note paper will mostly answer the purpose. In paper which is not close, such as filter or blotting paper, the fine perforations are not well seen. With a machine and a large jar, still more with a battery, very stout paper, playing cards, and even several thicknesses of note paper, may be perforated. The object to be perforated is placed upright upon the table of the universal discharger, the opposite ends of the two wires are moved until they press against the object on either side, and the discharge is conducted precisely as in the experiment for fusing the strip of tinfoil.

With a single good-sized Leyden jar of very stout glass it is even possible to perforate a glass plate. Glass being a bad conductor, it

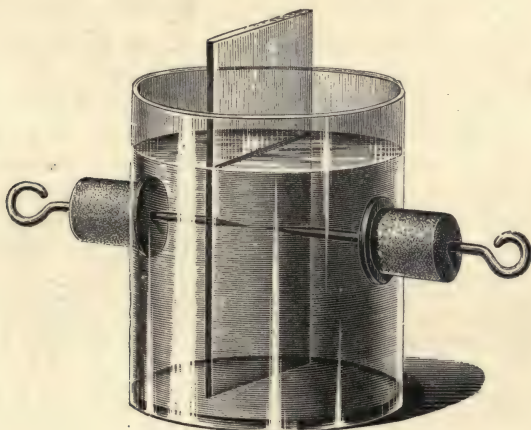


FIG. 331 (*an. proj.*; $\frac{1}{2}$ real size).

presents considerable resistance to the passage of electricity through its substance, and it is therefore in this experiment first of all necessary to assign to the discharge the shortest route possible; this is done by arranging the two pointed ends of the wires, between which the spark has to pass, so as to be in close contact with the glass and exactly opposite to each other. Next, the plate must be very thin, the thinnest window glass obtainable, and, further, care must be taken that the discharge does not find its way round the edge of the glass, either through the air or along a conducting layer of moisture which may possibly have collected upon the plate. In order to prevent this, the ends of the wires may each be surrounded by a little resin fixed on each side to the plate; it is, however,

better to surround the plate by an insulating liquid, such as olive oil or paraffin oil. Fig. 331 represents such an arrangement. A small tumbler is perforated by two holes opposite to each other. Corks are fixed into the holes through which the straight pointed ends of two wires pass, which are bent into rings at the outer ends. The points of the wires must be carefully adjusted until they are exactly opposite to one another. The glass plate being slightly warmed is introduced between the points, these are moved until they touch the plate, and the insulating liquid is poured into the tumbler until the latter is nearly full. Two chains connect the rings with the external coating of the Leyden jar, and one knob of the discharger respectively. The jar must be charged as strongly as possible, and the whole of the contrivance should be set up close to the machine, in order to avoid the loss of electricity which would occur if the jar had to be carried any distance. The jar may be arranged by suitable supports so that its knob may touch the small brass ball of the conductor of the machine, and a chain which is attached to one ring in the apparatus for the perforation is wound several times round the outer coating of the jar. The connection of the other ring with one knob of the discharger is also made previously to charging the jar. All being thus in readiness, the discharger is held in the left hand, the machine is worked by the right until the jar is strongly charged, when the free knob of the discharger is quickly brought near to the knob of the jar. When the experiment succeeds there will be a fine hole through the plate, from which usually several cracks spread in different directions.

The mechanical perturbation of a liquid by the discharge requires a very powerful charge of the jar or battery used for the purpose. Insulating liquids scarcely permit the passage of the discharge; water is therefore generally used for the experiments. A discharge which takes place in water between the opposite ends of two wires separated by a considerable distance is retarded and weakened, for water, although a conductor, is a worse conductor than metals, and as the electricity has in this case to traverse a great distance, the effect of the inferior conductivity of water upon the discharge becomes appreciable. But if the wires are

near together a spark passes between them in the water, and the water is violently agitated. If the jar can only be charged by an electrophorus, the contrivance represented in fig. 332 may be used; with a stronger charge that shown in fig. 333 should be employed.

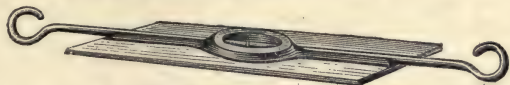


FIG. 332 (*an. proj.*; $\frac{1}{2}$ real size).

In fig. 332 a glass plate, which is clamped horizontally in the retort-stand, carries two wires each with a ring at one end; their other ends are filed round and arranged at a distance of only $0^{\text{mm}}\cdot 5$ from each other. These ends are surrounded by a small wall of sealing-wax, which forms a shallow vessel into which water may be poured. By means of the discharger and two chains the discharge is made to take place in the usual manner, and when the charge is strong a drop of water is projected upwards to a considerable height.

Fig. 333 represents a small glass vessel which carries upon its sides two clamps made of wire. The ends of the wires in the water are doubled back and are only about 1^{mm} from each other. The vessel filled with water is placed upon the table of the universal discharger, whose metallic rods are brought into contact with the clamps on both sides. When the discharge takes place, then, according to its strength, the water may be set into a more or less strong undulatory motion, or a portion may be thrown out of



FIG. 333 ($\frac{1}{2}$ real size).

the vessel, or if the charge be very strong, the disturbance of the water may be so violent as to break the vessel.

For the contrivance fig. 332 the wires are prepared first, the straight ends being filed neatly round. The plate, which may, of course, be of any shape, not necessarily square, is heated to the melting point of sealing-wax, and a small ring of the wax is laid on in the middle, with two branches extending in a straight line on opposite sides of the ring. When the wax is cool the wires are heated to the melting point of sealing-wax and placed in position upon the lines of sealing-wax on the plate. When they are fixed in the sealing-wax more of the wax is laid on the ring until it forms a wall about 3^{mm} high. The distance of the points of the wires must not exceed that mentioned previously, or no powerful discharge will take place.

For the glass vessel in fig. 333 one of the small drinking vessels used for cage birds may be employed. The clamps are made of brass wire which has not been softened in the flame; the form into which the wire is bent is seen from the figure. They should be somewhat elastic, so as to ride firmly on the glass, and after they are once adjusted care must be taken not to displace them again when the vessel is placed on the little table of the discharger. Even for strong charges the distance of the wires should be but small.

The disturbance caused when the electric discharge passes through air may be shown by a contrivance which differs from that in fig. 330 only in this, that the two wires are not connected by a strip of tinfoil, but are bent so as to approach one another very closely at the ends, 1 or 2^{mm} for small charges, a little more for powerful ones. A weak discharge makes the drop of water oscillate to and fro, a stronger one convulses the air in the bottle so much that the drop is projected out of the tube.

With very strongly charged jars the apparatus in fig. 327 (often called the 'electric mortar') may be employed to exhibit the mechanical action of the discharge upon air. A cork, a few millimetres wider than the

cavity in the wooden block and 10 or 15^{mm} long, is placed upon the mouth of the cavity. When the discharge takes place the cork is either lifted for a moment by the disturbed air or thrown entirely off.

Another effect may here be briefly mentioned; more will be said about this subject farther on. If the discharge is directed through a wire which is coiled round a small bar or needle of hard steel, the needle becomes *magnetic*, that is, it acquires the property of attracting and supporting small particles of iron, such as iron filings.

A wire of copper, or brass which has been softened in the flame, is spirally wound round a glass tube, as in fig. 334, the coils (twenty or more) being about 1^{mm}.5

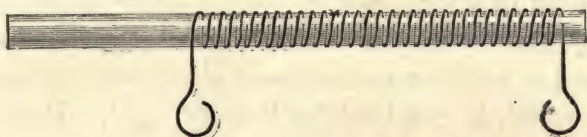


FIG. 334 (*real size*).

distant from each other. A short piece at both ends of the wire is left to hang straight down, and both extremities are bent into rings, to which chains may be hung for connecting the wire with the external coating of a jar at one side and with the knob of the discharger at the other. The free part of the glass tube (on the left of the figure) is clamped in the retort-stand, and a knitting needle or stout darning needle is placed inside the tube within the portion round which the wire is coiled. When the discharge has taken place, and the needle is taken out, it will be sufficiently magnetic to attract a few iron filings.

Needles purchased in the shops are sometimes already magnetic; but if the needle used be tested before the experiment, by holding

it close to some very fine iron filings, all possibility of deception will be avoided. For this experiment it is quite sufficient if the jar has been charged by an electrophorus.

The velocity with which electricity passes through good conductors is astoundingly great, and consequently the time required for an electrical discharge is exceedingly small. Only by means of specially devised and complicated apparatus is it possible to measure the indefinitely small intervals of time which are the subjects of observation in these experiments, and for their description the student must consult other works. As one of the results of these experiments, it may be stated that the electricity of a Leyden jar passed through a wire 380^m long in 0.0000000868 second; this gives for the space passed over in one second the enormous velocity of nearly 440 millions of metres or about 280,000 English miles, which is greater than that of light. It appears, however, that there is no such thing as a definite velocity of electricity. The time which elapses before an electrical change produced at one end of a conductor becomes perceptible at the other end, depends not only on the nature and dimensions of the conductor, but also on the nature and position of neighbouring bodies.

The duration of the spark has been found to be not greater than 0.00014 second, and not less than 0.00002 second. That the duration is extremely short may be proved by a very simple experiment. The disc shown in fig. 296 is fixed to the plate of the whirling table, which is turned by an assistant as fast as can be done, the room in which the experiment is made being as nearly dark as possible. The disc is then illuminated for an instant by a spark, the jar being held with the

knob downwards above the disc, and discharged with the common discharger. Each of the white and black quadrants on the disc appears by the light of the spark sharply defined, however fast the apparatus may be turned.

We may assume that the whirling table may be worked so that the disc makes about ten revolutions in one second, and that hence the time required for the disc to move through the twelfth part of a circle is about 0.008 second. If, therefore, the duration of the spark were 0.008 second, a particular quadrant would not be seen in its true magnitude, but would, in consequence of the persistence of the visual impression, appear to cover an additional space equal to that through which it moves in that time; in other words, each quadrant would appear broader by $\frac{1}{12}$ th of the circle or $\frac{1}{3}$ rd of its own magnitude, and the result would be that black and white would partly merge into one another. But since each quadrant appears perfectly sharply defined, the disc cannot have moved through any appreciable distance during the time that it was illuminated by the spark, that is, the duration of the spark must have been much less than 0.008 second.

Our atmosphere nearly always contains free electricity. Nothing certain is known about the origin of atmospheric electricity, but its existence may nearly at all times be easily proved by an electroscope provided with a collecting apparatus. The observer should betake himself into the open air, and station himself in a commanding position, such as the top of a hill, but avoid the vicinity of trees, shrubs, houses, etc.; it is then only necessary to raise the electroscope above the

head, holding it in a vertical position, to obtain signs of electricity by the divergence of the gold-leaves.

As collecting apparatus, a cork carrying a needle, as described at page 589, may be used. The apparatus collects still better if a bit of pastille, about 2^{cm} long, be stuck upon the point of the needle and ignited.

During fine weather the atmosphere contains more electricity in winter than in summer. Clouds are in general always electrified, and especially during the hotter season great quantities of electricity are accumulated in the clouds; when, as occasionally happens, the electricity of clouds is discharged, a vast electric spark—‘lightning’—is seen. The discharges which produce lightning occur sometimes between two clouds and sometimes between a cloud and the earth. The effects of lightning take place on a much grander scale than those of small artificial electric discharges, but they are of a similar kind; bodies which are very inflammable are ignited, bad conductors are fractured and scattered, good conductors, when thin (bell-wires, telegraph-wires), are fused.

Good conductors of sufficient thickness, such as iron rods having a section of from two to four square centimetres, or cords of twisted copper wire of 0.5 or 1 square centimetre section, are traversed by the quantity of electricity in the lightning without being destroyed, and since experience has shown that electricity is not only attracted by prominent objects, but travels in preference through the best conductors, such metallic rods are used as ‘lightning-conductors,’ for the protection of buildings against being struck by the electric discharge. A lightning-conductor to be efficient must satisfy three con-

ditions; first, it ought to be so large as not to be melted or ruptured if the discharge passes; second, it must be considerably higher than the highest or most projecting parts of the building which it is to protect; third, its lower extremity must be in well-conducting connection with the ground. It should, therefore, not be led into dry soil, but if possible into a well or brook in the neighbourhood of the building. When such a termination cannot be had, the foot of the conductor is usually sunk into a deep hole filled with wood-ashes, which conduct very well.

B. Contact-Electricity.

48. *Contact-Electricity. Galvanic Element. Galvanic Current.*—Friction and induction are not the only modes of developing electricity; it may also be produced by the contact of certain bodies of different kind. This mode of generating electricity was discovered by the observations of Galvani, and electricity produced by contact of bodies is hence often called ‘Galvanic Electricity.’ The electricity developed by contact is essentially of the same nature as the electricity produced by friction, but there exist important differences between them, both as regards the quantity that can be accumulated on a given conductor, and also as regards the quantity that can be produced in a given time. As a consequence of these differences, many effects may be more easily produced by frictional than by galvanic electricity, and, *vice versâ*, effects of galvanic electricity can only with great difficulty be obtained by frictional electricity.

When two different metals are partially immersed

in a liquid which is a good conductor of electricity, both metals become electrified, one of them positively, the other negatively. The two electricities which neutralised one another in each body are separated at the moment of contact with the liquid, and to the force which causes the separation, the name *Electromotive Force* has been given. If the two metals are copper and zinc, and the liquid water, the copper is charged positively, the zinc negatively. The quantity of electricity in each metal is exceedingly small; it is many thousand times less, even when large plates of the two metals are used, than the quantity of electricity in a rubbed glass rod. The small charge being diffused over a large surface, the electrical tension is accordingly very small, and the electricity is incapable of traversing even the smallest space filled with air, hence no spark is produced. In order to prove the existence of so feeble a charge directly by means of the electroscope, the instrument must be much more sensitive than the common gold-leaf electroscope; in fact, special instruments are required for the purpose, too expensive and complex for description in this work. Nevertheless it is possible to collect, by means of a condensing apparatus, so much of the electricity generated by the contact of copper and zinc with a liquid, that its existence may be demonstrated with the gold-leaf electroscope.

The apparatus used for the purpose—usually called simply a ‘condenser,’ while to other condensers special names are given (Leyden jar, etc.)—consists of two circular plates of metal, having the surfaces which are turned towards each other very evenly ground

and covered with a thin insulating layer of shellac. The lower plate is supported by an insulating pillar, to the upper an insulating handle is attached. The apparatus is therefore very similar to that in fig. 322, but that the single projecting insulating plate, which is rather thick, is replaced by two very thin insulating layers which need not project beyond the plate, because the tension is in this case so small that a passage of the spark across the edges of the intervening insulator cannot take place.

Metal plates cannot well be made quite flat and smooth without a turning-lathe and some skill in the work; but we may use plates of stout window-glass, each 8^m in diameter, and cover them with tinfoil. The plates are prepared exactly like the adhesion plates (see page 155); they need not be polished with jeweller's rouge, but some care should be bestowed upon the grinding of the edges, which must be very smooth. A pillar and handle of sealing-wax are fixed as in the condenser, fig. 322; they must be attached before covering the plates, or the tinfoil would come off when the plate is heated to the melting point of sealing-wax.

To avoid breaking the sealing-wax while the plates are being covered with tinfoil, they should be placed upon some support which has a suitable aperture, for example a filter-holder or a wide-necked bottle. Upon each plate a disc of tinfoil is laid, having its diameter 20 or 25^{mm} larger than that of the plate. Before placing the tinfoil upon the plate, in order to ensure a perfectly smooth contact between them, attention should be paid that no particles of dust adhere to either plate or tinfoil, and that no hard granules are in the layer of paste. The tinfoil is now pressed gently upon the plate with the finger, beginning in the middle and drawing the finger in all directions towards the edge. As soon as the middle portion is pretty firmly attached, the tinfoil is bent over the edge upon the back of the plate, using only moderate pressure. When the edge of the tinfoil is thus turned over all round the plate, and attached to the back, the operation of pressing the tinfoil everywhere close to the plate must be repeated until the paste has been squeezed out from between glass and metal as thoroughly as possible. Gradually greater and greater pressure will be required for this purpose, and in leading the finger from the middle, it is essential that

it should not stop near the edge and then be moved across the edge to the back of the plate, as in the first operation, but it should *in one continuous movement* proceed from the middle, across the edge, and along the back, to where the tinfoil ends. This must of course be done repeatedly and in every possible direction, until no more paste can be squeezed out. Afterwards a round disc of tinfoil is pasted upon the back of each plate; it is about 1^{cm} less in diameter than the plate, and has in the middle a hole about 3^{cm} wide, which allows of its being passed over the handle.

The insulating layer should be as thin as possible. The best way is to varnish the free surface of each plate with the clear portion of shellac solution, as has previously been described for glass (see page 561); but extreme caution is required to heat the plates only just sufficiently to dry the varnish without rendering it turbid and dull; the slightest over-heating blisters the tinfoil, renders the surface uneven, and therefore the whole useless. A thin uniform coat of solution of sealing-wax (see page 561) is more easily produced than the layer of shellac varnish, but it is inferior for the present purpose. One or two coatings, laid on at intervals of about twenty-four hours, will be required to render the insulating layer uniform.

The edges of each plate should also be varnished, but not the back. The stick of sealing-wax which carries the lower plate is last of all fixed to a wooden foot.

It has already been stated that a piece of zinc becomes negatively charged, and a piece of copper positively, if they are immersed together in a conducting liquid. The same happens if the two pieces of metal are not immersed in the liquid, but placed otherwise in contact with it. The most simple mode of producing not only contact of the metals with the liquid, but also of connecting them at the same time with the condenser, is that represented in fig. 335. Two strips, one of copper, the other of zinc, *k* and *z* in the figure, each 6^{cm} long and 1^{cm} wide, and bent as in the figure, are provided with handles of sealing-wax; at the ends which are bent they touch the condenser, and at the other ends which are straight they hold between them

a piece of blotting paper, folded several times and saturated with water, or salt water, which acts better than pure water. The paper plays no part in the development of electricity, it is there to prevent direct contact between the two metals; for if direct contact were to take place, the separated electricities would recombine instead of moving to the two plates of the condenser.

The electromotive force called into action when contact takes place between the liquid and

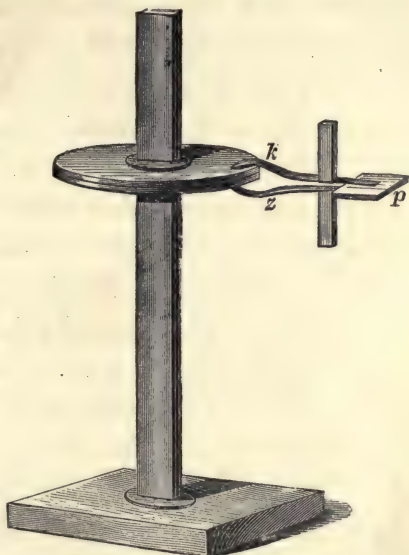


FIG. 335 (*an. proj.*; $\frac{1}{3}$ real size).

the two metals can, as has already been stated, produce only a very small tension, and can only generate very inconsiderable quantities of electricity in each metal plate. When these plates are connected with the condenser, the greater portion of the electricity of each kind which is generated passes from them to the plates of the condenser, where they both become bound by their mutual attraction. Electricity is thereby withdrawn from the two metals, but as the action of the electromotive force continues, new quantities are generated which again flow off to the condenser; and this goes on until the tension in the plates of the condenser, notwithstanding that the two electricities are mutually bound by each other, has become as great as it was before in the

two metals. For if electricity is withdrawn from the metals, so as for a moment to diminish the tension, the electromotive force instantly reproduces whatever tension of electricity it is capable of producing. In fact a second is more than sufficient to charge the condenser as strongly as it is possible to charge it under the circumstances of the experiment.

The condenser being thus charged, the pieces of copper and zinc are placed aside, and the upper plate of the condenser is lifted straight up by its insulating handle and brought in contact with the knob of the electroscope; a divergence of the gold leaves takes place, for the two electricities which were condensed and bound in the apparatus are set free by the lifting of the upper plate, and the free electricity of the latter is communicated to the electroscope. The quantity of free electricity, in spite of the condensation which took place, is nevertheless so small that it causes a divergence of only a few millimetres. If, as has been assumed in the figure, the upper plate of the condenser has been charged by the copper plate, it communicates a positive charge to the electroscope. This may be proved by bringing a rubbed glass rod near the electroscope; it increases the divergence of the leaves. An examination by the electroscope of the lower plate of the condenser, which was in contact with the zinc, shows it to be charged with negative electricity.

It requires considerable care to exhibit the galvanic electricity in these experiments, on account of the smallness of the quantities of electricity generated. The insulation should everywhere be perfect, and must be examined before the experiments. See that no liquid from the paper has dropped upon the metal strips close to the condenser, or upon the sealing-wax handles. The insulating surfaces

of the condenser plates should be perfectly dry. In lifting the upper plate it must be held quite parallel to the lower plate, for if one portion of the edge is raised while another still remains in contact with the lower plate, recombination of the two electricities is apt to take place through the thin layer of varnish at the place of contact.

The knob of the electroscope must, in all cases when electricity is to be communicated to the instrument from a condenser, be touched by the *unvarnished* portion of the plate; the upper plate, therefore, after it is raised, must be turned with the handle downwards, and the knob touched by it while it is held in this position. For moistening the blotting paper a solution is made of a few grains of common salt in a few drops of water. The paper should be held with the forceps while it is moistened and placed upon the strip of zinc, so as to avoid making the fingers wet, and by them wetting the sealing-wax handles.

An arrangement for producing electricity, consisting of two metals and a conducting liquid, constitutes a *galvanic element* or a simple *galvanic circuit*. The two metals are called the *poles* of the element, the copper being the positive pole, the zinc forming the negative pole. Besides metals, some other substances—carbon, for example—may be used in a similar manner for producing electricity.

When two galvanic elements are arranged in such a manner that the zinc of one element is in conducting connection with the copper of the other, twice as great an effect is produced as by a single element, for although the two connected metals no longer give electrical indications, the copper of the first element is found to be twice as strongly positive, and the zinc of the second twice as strongly negative, as before, when there was only one element. A suitable combination of a series of galvanic elements is called a *galvanic battery*. Fig. 336 represents a battery of six elements. The copper of the first element, and the zinc of the last, are

six times as strongly electric as is the case in a single element. The pole of one element being soldered to the opposite pole of the next, only the terminal strips of metal are free in such an arrangement, and they are called the 'poles of the battery.'

Six very small test-tubes are placed side by side in holes bored with the centre-bit into a pretty stout piece of board. Six strips of copper and six of zinc are cut out of thin sheet metal, each from 5 to 8^{cm} long and 2 or 3^{mm} wide; five of the strips of zinc are soldered each of them to one of the strips of copper, allowing

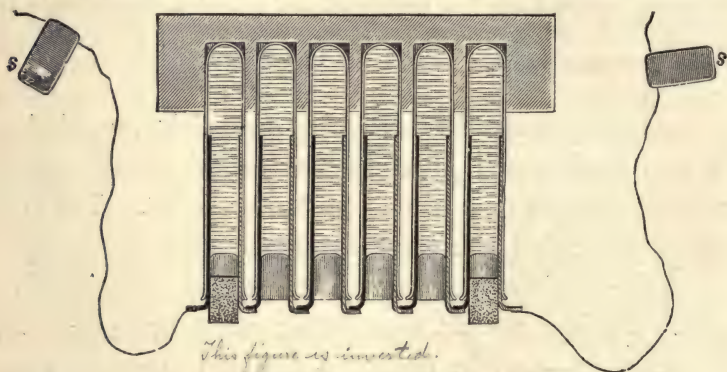


FIG. 336 ($\frac{1}{2}$ real size).

the ends to overlap each other for a few millimetres. The sixth strip of each metal is left free, and forms respectively one of the poles of the battery; each of them has a thin copper wire, from 15 to 25^{cm} long, soldered to it, and near to the free ends of the copper wires small pieces of sealing-wax, *s s* in fig. 336, are fixed. The joined strips are bent as shown in the figure, and each test-tube must contain a strip of each metal. The two single strips form the terminals, one being placed in the first and the other in the last test-tube. The two different metals in each test-tube must not be allowed to touch each other; their contact is prevented in the tubes at the end by fixing small corks between the metals; in the intermediate tubes they cannot touch each other if a little care has been given to bending them accurately and straight. The corks used in the terminal tubes should only fit loosely, or they press the hard and angular strips too strongly against the sides of the test-tube, and these may get broken. The liquid used is salt water, which is introduced very carefully by means of a pipette, so as not to moisten the tubes on the outside.

The charge given to the plates of the condenser, if the two copper wires are held by the insulating pieces of sealing-wax, and brought into contact one with the upper, the other with the lower plate, is six times as great as in the first experiment, and consequently the divergence caused by touching the electroscope with one of the condenser plates is now pretty considerable.

When the two poles of a galvanic circuit, which may consist of one or several cells, are connected by a conducting body, the circuit is said to be 'closed,' and in this case the two electricities pass through the connecting body and recombine. This movement is called the *galvanic current*. It resembles the recombination of the two electricities in a Leyden jar or battery of jars, but is very much weaker; but on the other hand it continues as long as the circuit is closed, that is, as long as the poles are in conducting connection, while the discharge current previously considered lasts only for an extremely small fraction of a second. Every electric current is properly speaking a double current: positive electricity flows in one direction, negative electricity flows in the opposite direction. For the sake of clearness and brevity, the positive current is designated simply as 'the current,' if the direction of the current is spoken of, it being always understood that an opposite current, the negative one, exists simultaneously. Thus in one copper-zinc couple we should say, *the current flows from the copper pole through the connecting wire to the zinc pole*; or, in other words, positive electricity flows from the copper through the connecting wire to the zinc, and negative electricity flows from the zinc through the connecting wire to the copper.

As a consequence of the small tension of galvanic

electricity, only the best conductors can be easily traversed by it. Through paper, wood, the skin of the human body, and similar substances, current electricity is so little able to travel that these bodies behave in reference to it like insulators. Even pure water is a bad conductor of galvanic electricity. Metals, carbon, and solutions of salts and acids (sulphuric, nitric, and hydrochloric), concentrated or dilute, are the only bodies available for conducting galvanic electricity. The solutions of salts and acids are by far better conductors than pure water, but even their conductivity is many hundred thousand, and even many million times less than that of the metals. Of all known substances silver is the best conductor of galvanic electricity; copper stands next and very near to it in conducting power. Copper wire is preferably used for conducting galvanic electricity, not only on account of its excellent conductivity, but also because the malleability and ductility of the metal is so considerable that it is easily brought into any desired form,

When conducting wires of copper are connected with other bodies, the metallic surface in contact must always be perfectly clean and bright, free from verdigris or other deposits, because these conduct electricity badly. The ends of copper wires which are used in galvanic apparatus, or in experiments on galvanic electricity, should therefore frequently be rubbed with sand-paper or scraped with a blunt knife.

Another condition needful for good conduction is that the connected conductors should be kept in firm and close contact; a mere suspension or loose attachment of one body to another, as is permitted in experiments on frictional electricity, would be altogether insufficient and cause nothing but failure. The wires are therefore in galvanic apparatus always fixed by *binding screws*.

Various forms of such binding screws are represented in fig. 337. The form *A* is most easily made. Into a piece of sheet brass, 45^{mm}

long, 15^{mm} wide, and 3^{mm} thick, a hole is drilled 8^{mm} from one end and a hollow screw cut in it with the smallest of our screw-taps (see page 94), or the middle-sized one. A piece of wire of suitable diameter, and 3^{cm} long, is softened in the middle over the flame and bent at right angles, clamping it in the vice and using the mallet. The bent wire is clamped in the vice, so that one half lies horizontally between the jaws and the other half stands out vertically, and a screw is cut on the projecting half, which corresponds to the nut previously cut. The piece which contains the nut is then bent into the shape shown in the figure; the side where the nut is must

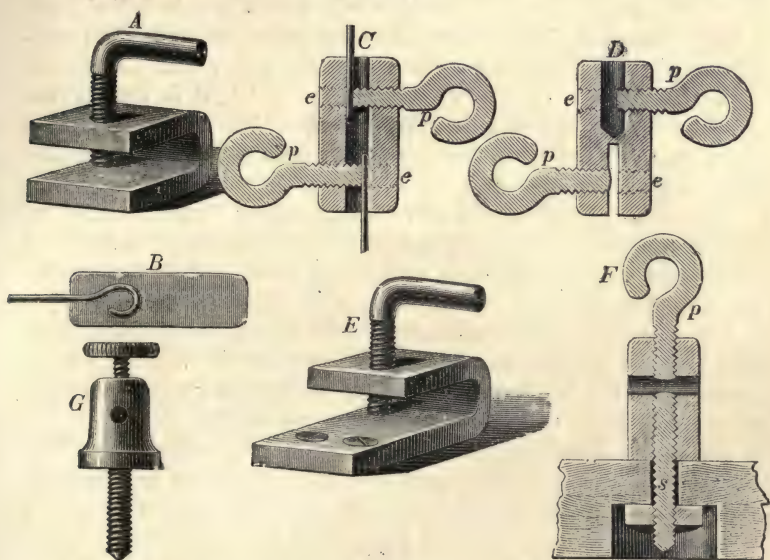


FIG. 337 (*A, E, an proj.*; *A to G real size*).

be clamped up to about 18^{mm} from the end in the vice between leaden cheeks, in order to protect the nut, and the projecting portion bent by hammering it with the mallet until it is horizontal. The piece is then taken out of the vice, and both halves are hammered together over a flat piece of hard wood, about 5^{mm} thick, until they are parallel, as in the figure. This operation may be rendered easier by softening the metal previously; but in afterwards using the clamp the screw should never be drawn very tight, or the two halves will be forced away from each other. This simple kind of binding screw cannot be used for clamping the wires themselves; but if the ends of the wires have flat pieces of sheet copper soldered to them, in the

manner shown at *B* in the figure, they fulfil every requirement. The flat terminal pieces of the wires are simply placed between the end of the screw and the inner side of the clamp, and the screw is turned until the terminals are held with firm pressure.

The other binding screws are made of brass wire, 10 or 12^{mm} thick, of which pieces of suitable length are cut with the metal saw or the narrow cut edge of a flat file. Holes are drilled through the pieces, nuts cut in them with the smallest tap, and the necessary screws for them are made of brass wire. The handles of the screws are made by softening the wire and bending one end into the form of a ring; the portion of the wire which is to be left straight being clamped in the vice, the projecting end is brought into the required shape by bending with the round pliers and hammering with the mallet. As the wire is rather thick, it is usually not possible to close the ring by this operation, but by proceeding as has been described when making a pinchcock (see page 21), a complete ring will be formed.

Fig. 337, *C*, is the section of a binding screw for connecting two wires; a hole into which the ends of the wires are inserted is drilled lengthwise through the little cylinder of brass, and the two screws for clamping the wires enter from opposite sides.

Fig. 337, *D*, serves for connecting a flat terminal with one of wire. The hole for the wire reaches from one end to the middle; for the reception of the flat terminal, a slit is cut down with the metal saw from the opposite end of the cylinder, about 12^{mm} deep.

The forms *E* and *F* in the figure are intended to be attached to the wooden parts of the apparatus used. *E* serves for clamping flat strips of metal, and differs from *A* only in having the lower part longer, so as to be capable of being fixed by means of two wood-screws. In order that the flat heads of the screws may not project, the entrance of the holes in the clamp must be enlarged and made funnel-shaped. This operation is performed with the 'rose counter-sink;' fig. 338 shows the conical cutting portion of it with its triangular facets. The handle may be fixed into a brace or simply worked by a strong drill-bow, exerting moderate pressure upon the instrument until the funnel-shaped entrance is of the requisite width.



FIG. 338
(real size).

In form *F* the upper screw serves for clamping wires, which are inserted from the sides into a horizontal hole. The lower screw is used for attaching the binding screw to the apparatus, which may be done either by simply screwing it like a common screw into a hole made in the wood, or by boring, from one side of the piece of wood, a hole through which the screw just passes, and, from the

other side of it, one large enough to receive a square nut of brass 3^{mm} thick, by means of which the binding screw may be drawn tight to the wood.

To make a binding screw like *F*, two holes must be drilled through the brass cylinder, one along the axis, the other at right angles to it. The former of these is tapped into a nut, and the screw *s* is put in from below and fixed with a little soft solder. The screw *s* should just reach to the bottom of the hole made across the cylinder, so that the wire to be clamped in the hole may rest upon the top of *s*; if the screw *s* did not reach quite up to the level of the horizontal aperture, any wire clamped by the screw *p* would be pressed down into the space left vacant above the end of *s*, and might be easily broken. A similar precaution is necessary as regards the binding screws *C* and *D* in the figure; the holes for the pressure screws *p* must only just reach those for inserting the wire which is to be clamped, and consequently the hollow screw should be made with the 'middle tap,' that is, a tap with only just a few threads at the end (see page 94). Such a tap is, however, very easily broken off, and a way out of the difficulty is to tap the nuts right through, and then to insert from the other side small bits of brass wire with a thread cut on them, marked with *e* in the figure, in which the part of the nut to be made at first, but then to be filled up in this way, is indicated by dots. The best way to obtain these little bits of screw is to cut a screw of the necessary width upon a longer piece of brass, screw it into the hole as far as required, cut off the part left outside with the saw, and smooth the outside afterwards with the file. If the piece fits well into the hole it will remain firm by itself, otherwise a little solder should be used. Only a very small quantity of solder must in any of these cases be used, so that none of it may run into the hole in which the pressure screw *p* is to move.

A form of binding screw which can only be made upon a lathe is represented at *G* in the figure. It is one of the kinds usually sold by the dealers, and differs from the others only by its more elegant shape, and in having instead of a ring a flat milled head for turning the pressure screw.

Conducting wires for galvanic apparatus require no insulation; they may rest on the table and be touched with the hand provided the hand is dry. A special insulation is however required where the wires themselves are in contact, side by side, and the passage of electricity from one wire to the next is to be avoided. To insulate such wires they are covered with cotton or silk. Cotton insulates sufficiently well, but silk has the advantage of being more durable, and it is also thinner than a covering of cotton. The latter advan-

tage is the more important, as in many cases, which will be stated later on, it is necessary, for obtaining the greatest effect, to pack as much wire into a given small space as possible.

About 100 grammes of uncovered wire, $1\text{mm}\cdot5$ thick, and 50 grammes of covered, $0\text{mm}\cdot6$ thick without the covering, will be sufficient for the most important experiments. If more can be afforded, a quantity of covered wire having a greater thickness should be purchased.

The galvanic current produced by our battery of six copper-zinc elements is very feeble. Stronger currents, however, may be produced by other combinations, for example by *Grove's* or *Bunsen's elements*. In both of

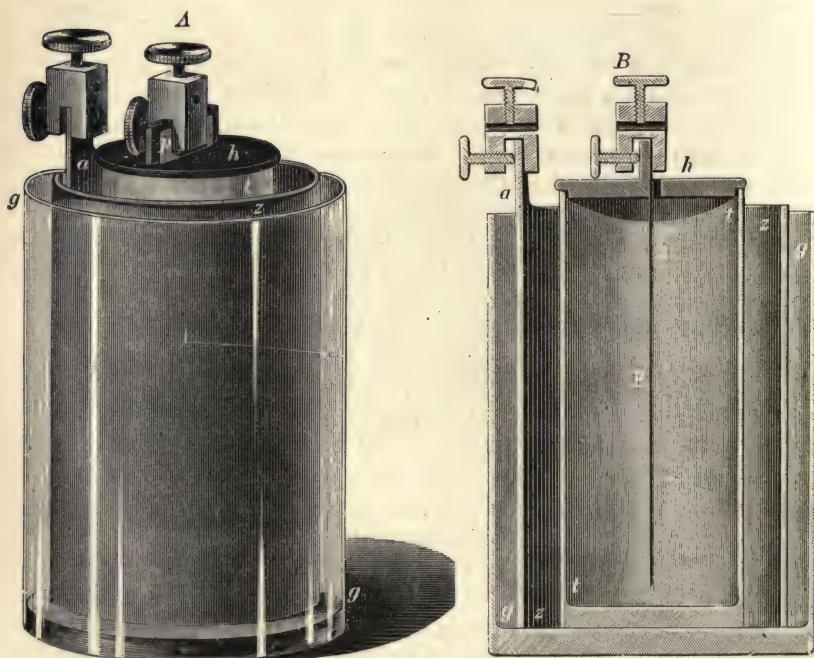


FIG. 339 A, B (*A an. proj.*; *A and B $\frac{1}{2}$ real size*).

them zinc forms the negative pole; the positive pole is formed in Grove's element by platinum, in Bunsen's by carbon, or rather a hard, dense, and well-conducting

variety of carbon. The two bodies which thus form the opposite poles are immersed in each of these ele-

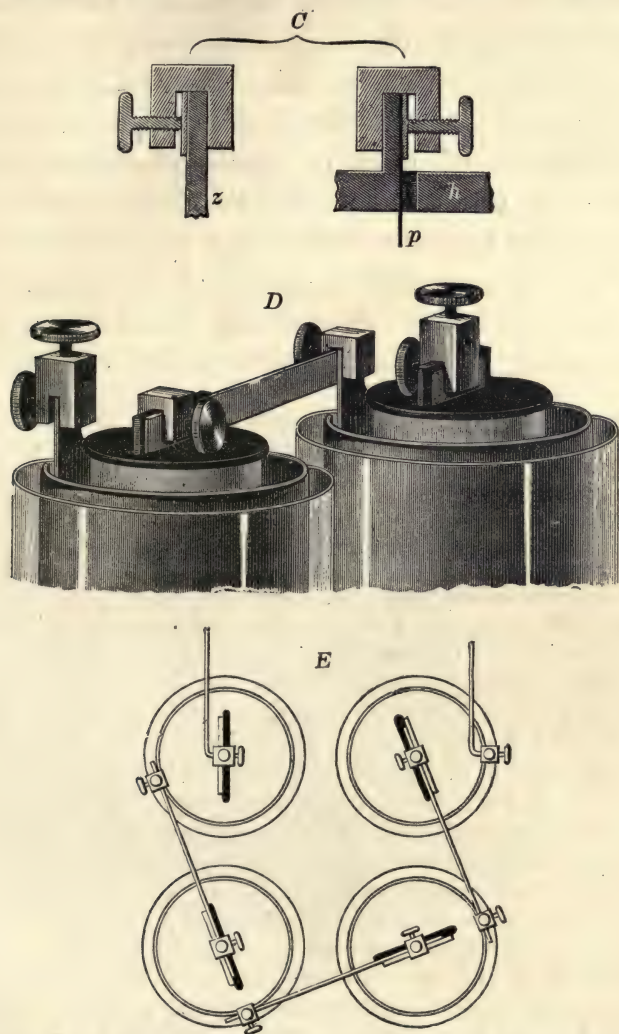


FIG. 339 C, D, E (C real size; D an. proj., $\frac{1}{2}$ real size; E $\frac{1}{4}$ real size).

ments in two different liquids, which must be in conducting communication, but are not allowed to mix

with one another. This is effected by using a thin cylindrical vessel made of unglazed earthenware; the vessel has only been slightly heated in the oven during the process of manufacture, and has therefore preserved the porosity of the material. This 'porous vessel,' which contains one of the liquids, is placed inside a second vessel of glass or glazed stoneware, which contains the other liquid. The two liquids thus enter the pores on opposite sides of the porous vessel, and come into contact without sensibly intermixing. The zinc stands in both kinds of elements in dilute sulphuric acid; the carbon or platinum in concentrated nitric acid.

The mode of action of these elements will be explained farther on. The following directions are, in the meantime, intended to enable the student to use the elements for the experiments on various effects of the galvanic current. There are great differences in the form, size, and mode of arrangement of the different parts of either kind of element; only one convenient construction of each kind will, however, be described here.

In fig. 339, *A* represents the exterior, and *B* a section of a Grove's element or 'cell.' In both figures *gg* is a glass vessel with stout walls, *tt* the porous clay cell, *zz* a hollow cylinder of zinc, which has either been cast in a suitable mould or bent into the requisite shape out of a sheet of stout zinc; a short projection *a* serves for attaching a binding screw to it. Within the porous cell is a sheet of platinum foil, *p*, fixed to a cover of ebonite, *h*, which rests on the porous vessel. The cover has a slit through which the platinum passes; by the side of the slit the cover bears a small vertical plate to which the top of the platinum strip may be clamped. When only one element is to be used, binding screws of the form shown in *A* and *B* are attached to the zinc and platinum; they are provided with holes for inserting terminal wires, and also with pressure screws for clamping the wires; but if several elements are united to a battery, binding screws of this kind are only used for the zinc in the last cell and the platinum in the first, while the intermediate connection of the elements is made by means of strips of sheet copper, which are clamped to the metals by more simple binding screws. Fig. 339, *C*, shows in section the parts thus connected. *D* is a view of the

connection between two cells, and *E* shows a complete battery of four cells, as seen from above. In clamping the platinum the metal is placed between the plate of ebonite and the smooth inner side of the binding screw, so that the pressure screw works against the opposite side of the ebonite plate, not against the platinum, which would be spoiled by it; again, when a strip of copper is to be connected with the platinum, the latter is first placed upon the ebonite, then the copper upon the platinum, and the clamp is set with its flat inner side against the ebonite, while the screw works against the copper; finally, for connecting with the zinc, the copper is placed upon the outside of the projecting zinc. These various directions will become quite clear if diagrams *B* and *C* in figure 339 are attentively studied.

Fig. 340 shows a Bunsen's cell with the terminal screws, which are provided with nuts, by means of which the connecting wires may be clamped to the binding screws.

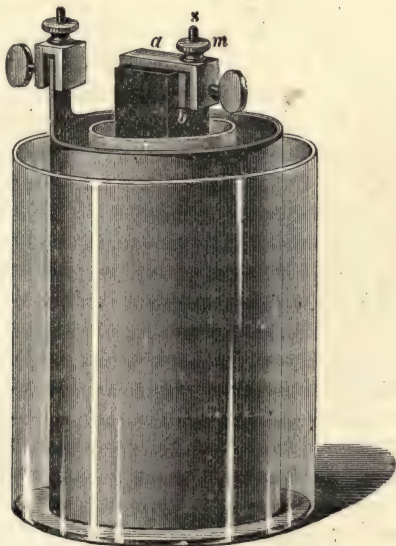


FIG. 340 (*an. proj.*; $\frac{1}{2}$ real size).

The carbon forms a rectangular four-sided prism; its terminal binding screw consists of a piece of brass, *a*, bent twice at right angles, and of a small rectangular plate, *b*, which has the spindle of a screw, *s*, attached to it. The spindle passes loosely through a hole in *a*, and carries the nut *m*, which can be turned by a milled edge. To clamp this binding screw, the nut *m* is loosened until the plate *b*

can be moved; the top of the carbon is then placed within the binding screw, the nut *m* lifted by the thumb and middle finger of the left hand until *b* is in close contact with the horizontal portion of *a*, and pressing *a* firmly down upon the carbon by means of the two last fingers of the left hand, the pressure screw is screwed tightly up with the right hand.

The outer vessel, the zinc cylinder, and the porous vessel are like the same parts in Grove's element, but there is no cover upon the porous cell.

Zinc, as we know, is dissolved by dilute sulphuric acid. While the circuit is closed, and a galvanic current passes, solution of zinc goes on, whatever the kind of element used, and consequently the zinc is gradually consumed and must be renewed. But the consumption of zinc may be prevented while the circuit is open, and the total consumption therefore considerably lessened, if the zinc is amalgamated, that is, covered with a superficial layer of an alloy of zinc and mercury. The zinc cylinders obtained from the dealers when purchasing galvanic elements are usually amalgamated; but if the student has to amalgamate zinc, he should dip it for a short time in dilute sulphuric acid, and then, holding it over a capacious vessel (a basin or pan), a few drops of mercury are poured upon the metal. If the acid has produced a clean surface upon the zinc, the mercury will spread itself out upon it at once; otherwise it is rubbed well everywhere over the surface, inside and outside the cylinder, by means of a little piece of cloth moistened by the dilute acid. The mercury left in the basin after the operation is alloyed with zinc, and should therefore not be poured back into a bottle containing pure mercury. Freshly amalgamated zinc is uniformly bright and silver white; on standing for a long time in the air it gets dull and grey, and a few small drops of mercury collect on the surface. If such grey zinc is placed again in dilute acid, the mercury diffuses itself again all over the surface, and the silvery colour is restored, but not the former brightness.

Of the effect of amalgamating zinc the student can easily convince himself by putting two thin strips of zinc, 3^{cm} long and 1^{cm} wide, one amalgamated, and the other not, into test tubes half filled with dilute sulphuric acid. The unamalgamated strip dissolves rapidly with brisk evolution of hydrogen, and finally disappears, while the amalgamated strip shows only here and there a few bubbles of gas, and remains almost intact for an indefinite time.

Amalgamated zinc which has become grey causes also effervescence at first, when placed in the acid, but this goes on only until the zinc has become white again.

The sulphuric acid must be diluted in the manner explained on page 224. After the porous cell is placed inside the outer vessel, this is filled to about 2 or 3^{cm} from the top with the dilute acid, pouring it in through a funnel, and holding the porous cell in its place by pressing the finger upon it, or otherwise the cell will float, and it is impossible to see whether the proper quantity of acid has been poured into the outer vessel. The porous cell is then filled with crude concentrated nitric acid, also using a funnel for the purpose; in Grove's element this is done *before* the platinum strip is introduced, but in Bunsen's the carbon, already provided with its binding screw, is first placed in the cell, and the nitric acid poured in *afterwards*. The end of the funnel should be held close to the edge of the vessel for a short time before it is removed, so as to avoid dropping any of the nitric acid upon the zinc, binding screws, connecting wires and copper strips, or into the dilute sulphuric acid. The metal parts just mentioned are all strongly attacked by nitric acid, and the dilute sulphuric acid, when it contains an admixture of nitric acid, acts destructively upon the amalgam. If nitric acid should accidentally have dropped upon any of the metallic parts, it should be washed off immediately with water, and the surface of the metal cleaned and dried; the dilute sulphuric acid into which any of the nitric may have dropped must be taken out.

The sulphuric acid may be constantly used during several hours for the maintenance of a galvanic current; but as the circuit is generally closed only a small portion of the time during which the battery is in use, the same acid will serve for a considerable time. After taking the elements to pieces the sulphuric acid may be left in the vessels in which it was, provided these are placed so that they cannot be upset. As soon as crystals (of zinc sulphate) begin to be deposited, the acid ceases to be of further use for the purposes of the battery, and must be poured out of the vessels.

The nitric acid is at first nearly colourless, but it gradually assumes a yellow colour by being used in the porous cell; this colour changes afterwards to a bluish-green, and finally the acid again becomes nearly as clear as water. When this disappearance of colour takes place the current becomes greatly enfeebled, and the nitric acid should be changed.

While the elements are in use red nitrous fumes are constantly evolved, especially after a time when the nitric acid is no longer very new. These vapours are suffocating, and attack metallic parts with which they come into contact. The battery should therefore not be placed within the room, but if possible upon the

ledge outside a window. The terminal wires may in that case be carried into the room by means of two holes through the lower part of the sash, or two strips of copper, 10^{cm} long, 10 or 12^{mm} wide, and 0^{mm}·5 thick, may be clamped between sash and window-frame, and wires leading to the battery and into the room may be soldered to the opposite ends of these. The two strips must of course be kept carefully apart.

When a Grove's battery is to be taken to pieces, first of all the binding screws are removed from the zinc; then the covers of ebonite are lifted out of the porous cells, together with the attached binding screws, platinum foil, and copper strips, allowing the platinum to rest a little on the edge of the vessels that all the acid may flow off, and finally these parts are separated from each other by loosening the clamps.

In taking Bunsen's elements to pieces the binding screws are also removed from the carbon pieces before these are lifted out of the acid. The zinc plates are taken last of all out of the sulphuric acid.

Immediately after separating the parts, the zinc cylinders, binding screws, ebonite covers, and copper strips must be rinsed in an ample supply of water; the zinc cylinders and covers are left for the water to drip off, and thus to dry, but the screws and copper strips should be wiped, after rinsing them, with a cloth, or dried as quickly as possible in the sun or before a fire. The platinum foils of Grove's elements are rinsed with water, placed upon a flat support, and wiped dry with a piece of soft cloth. The carbon plates and porous cells must be washed very carefully to prevent them being spoiled. They are left for several days in water, which is occasionally changed, and afterwards they are allowed to dry. If some time after they have become dry a white efflorescence should make its appearance upon the porous cells (either as a mealy coating or an incrustation of fine needles, or as a white fur), it shows that they have not been sufficiently soaked; the same applies to the carbon plates should they smell of nitric acid. In either case the pieces must be placed again for some time in water.

If the student can procure pans of sufficient size, and a suitable place for them, the best way is to preserve the carbon plates and porous cells constantly under water, which in that case need only be changed when the battery has been used.

The inhalation of nitrous fumes may be avoided during the time required for taking the parts to pieces by performing the whole operation in the open air, or at least near the open window. The pouring of the nitric acid from the porous vessels back into the

bottle, during which operation the evolution of fumes is worst, should in any case be done in the open air.

The bottle with the used nitric acid should be kept in a place where nitrous fumes can do least harm, for the stopper is apt to be lifted by the pressure of the nitrous acid gas which is given off by the acid, and the gas escapes. A cork must never be used for closing the bottle; it is soon destroyed by the action of the acid, and as long as it still closes the bottle so tightly that the gas cannot lift it, there is great danger of the bottle bursting by the pressure of the gas within.

Such of the clamps, copper strips, or pieces of wire as show a deposit of verdigris upon their surface, due to the action of the acids or acid fumes, must be well polished with fine emery-paper after they have been washed and dried.

In consequence of the high price of platinum, the platinum foils used for batteries are very thin. They require a somewhat careful treatment, for they are easily torn or apt to become crumpled. A creased foil is made red hot in the flame to soften it, and placing it upon the table it is smoothed by the finger-nail. The carbon pieces of Bunsen's battery are not liable to this disadvantage, but they require on the other hand some amount of trouble in washing them thoroughly out, and thereby always cause the loss of some acid which has penetrated into the porous mass.

The carbon plates are made of a very hard, dense variety of carbon, which is deposited in gas-retorts during the process of manufacture, and is designated as 'graphitoidal' carbon. The carbon is also to be had in the form of hollow or solid cylinders made of an artificially prepared calcined mixture of coke and bituminous coal, which is first finely powdered and then strongly compressed. These are not so dense as those previously mentioned, and the cylindrical form is also less convenient for the attachment of the connecting parts. It is therefore not advisable to purchase them, and still less any of the various combinations of elements constructed with a view to avoiding the inconveniences of Grove's and Bunsen's elements, or recommended as being cheaper than these. All these elements either produce a much feebler current, for example, the so-called chromic acid batteries, or they are still more inconvenient than those described, as for instance, the zinc-iron elements.

Two Grove's or Bunsen's elements are absolutely required for the experiments which will be described in the following articles. If the student can afford more, four or six, the experiments may be performed on a somewhat larger scale.

The size of the elements varies considerably. For experiments like ours, which are always on a small scale, Grove's elements of 12^{cm} height, and Bunsen's of 18^{cm}, are quite sufficient. When the current outside the battery has to traverse long and thin wires, as in experiments on telegraphy, or bad conductors, such as liquids, as when chemical decomposition is to be effected, small elements produce nearly the same effects as large ones; but if the connection is made by well-conducting, stout, short wires, as in experiments on the heating and magnetic effects of the current, large elements act much more powerfully than small ones.

For experiments on a large scale no general rules can be prescribed. The arrangement which is most suitable and economical for a given purpose may, however, be determined in each case, regard being had to the length, thickness, and conducting power of the connecting wires, and various other circumstances, according to two laws, respectively called *Ohm's* and *Faraday's* law, upon neither of which we can further enter in this work.

49. *Effects of the galvanic current upon conductors.*—

The galvanic current has so little tension that mechanical effects like the perforation of substances cannot be produced by it, for bad conductors are not traversed by it. In order to pass the current through the human body, the parts of the skin which are brought into contact with the terminals of the battery must be moistened at least with water, or better with salt water, to increase the conductivity. But even then the sensible effect is very small, and only a strong battery of a great number of elements will produce a shock. A feeble current, however, is sufficient to excite the nerves of taste of the tongue. The two terminals may either be placed side by side, 5 or 10^{mm} apart, upon the point of the tongue, or one may be placed across the middle of the tongue while the other is made to touch the point of it; in the latter case the effect upon the taste is particularly distinct at the point of the tongue touched by the wire. Either of the terminals, when

allowed to touch the tongue separately, is perfectly tasteless, but as soon as the circuit is closed by the tongue itself, the nerves of taste are thrown into a state of activity, and the sensation of a pungent taste is felt. The sensation is, however, somewhat different at the two terminals; at the negative terminal the taste is acid, while at the positive terminal the taste somewhat resembles that of caustic soda.

For this experiment the current of the small battery, fig. 336, is sufficient, or, still better, two Bunsen's or Grove's elements may be employed.

When a galvanic current passes through a metallic wire the wire becomes heated, but the heating effects of the galvanic current are more easily observed than those produced by the discharge of an electric battery, because the latter is instantaneous, whereas the current goes on for some time.

With powerful batteries, all metals may not only be heated so as to become incandescent, but even the least fusible of them may be melted and volatilised. The current of two Grove or Bunsen elements of moderate size is sufficient to render a copper wire, a few decimetres long and $0^{\text{mm}}\cdot5$ thick, sensibly hot. If a small strip of tinfoil, 3^{cm} long and 2^{mm} wide, be placed upon a wooden support, and first one terminal be pressed upon one end of the strip and then the other upon the opposite end, the strip becomes so hot that some part or other fuses; if the experiment be made in the dark, it will be seen that the fused portion as a rule becomes incandescent before it melts. An iron wire of 10^{cm} length and $0^{\text{mm}}\cdot2$ thickness is made red hot by the

same current, and one of the same thickness, but only 4^{cm} long, is fused and begins to volatilise.

It has already been stated that the tension of current electricity in an ordinary battery is too small to produce sparks. Batteries of several thousands of elements have been constructed, and by means of these a constant series of sparks has been obtained, passing between two terminals separated by a very small distance. Sparks are nevertheless ordinarily seen between the two terminals when contact is made and then again broken; frequently a minute spark is seen when the circuit is closed, but at any rate a spark appears when it is opened. The appearance of the spark in this case is due, not to incandescent air, but to incandescent metal; the two terminals touch each other only at a metallic point which is sufficiently heated by the current to become luminous and to be volatilised. When the terminals consist of copper wire, the sparks are very small and appear bluish-green; iron wires produce large scintillating sparks of a yellowish-red colour. With copper wires, brilliant yellow-red sparks, interspersed with tiny bluish-green luminous points, may be obtained if one terminal be pressed upon the uncut part of a smooth file near the handle, and the other is drawn over the cut portion so as to touch only the projecting points; in this experiment the points of the teeth of the file and the copper become incandescent at the same time.

When two pieces of some compact well-conducting variety of carbon are attached to the ends of the connecting wires, and gentle contact is made between them, a small but very bright luminous point appears

where the two pieces touch. When a strong battery of from 40 to 80 large Bunsen elements is used, and two pointed pencils of carbon, connected with the terminals, are brought close together, light of most dazzling splendour is emitted by the two points, such as cannot be obtained from any other artificial source. This 'electric light' is now frequently used for illuminating purposes on a grand scale, but is rather expensive; for not only is a strong current required for it, but also a somewhat complex apparatus for maintaining the distance between the two carbon points, which is at every moment, while the current lasts, increased by two causes. One of them is the wasting away of the carbon by the combustion that is going on, the other is that by the action of the current solid carbon particles are constantly transferred from one pole to the other; now it happens that the positive current has more power to transfer matter than the negative, and as a portion of the transferred particles is burnt, it follows that the positive pole becomes blunt, and even hollowed out, while the negative carbon pencil remains pointed by the slow deposition of carbon dust, although it does not really gain in size. The wasting away, particularly of the positive pole, in a short time renders the distance between the poles too great to allow of the passage of the current, and the light would be extinguished but for a contrivance which acts as 'regulator.' The transference of matter accounts for the fact that in producing a powerful electric light the points are first brought in contact, and are then separated again a few millimetres, without breaking the circuit. The carbon particles constitute a conduct-

ing medium between the poles, and the quantity of incandescent matter is thus much greater than it would be if mere contact of points were maintained.

For these experiments copper wires, not less than 1^{mm} thick, are attached to the poles of the battery. The thin copper wire which is to be heated may be simply pressed with the fingers to the free ends of the terminals, or, still better, two screw clamps are used, to which first the thin wire and then the stouter terminals are fixed. Clamps must, of course, be used when iron wire is to be made red hot or is to be fused, or the fingers will be burnt. The iron wire is first fixed in the clamps at both ends; one terminal is then screwed into one clamp, and the other is pressed by the hand upon the second clamp. The same piece of iron wire which has been rendered incandescent by the current cannot be fused easily in the next experiment unless it is previously made bright by polishing it with emery paper; the reason is that while it is red hot a thin layer of oxide of iron is formed on its surface, which is a bad conductor of the current.

For obtaining the brilliant speck of light between two carbon points (which with only two elements cannot give the least idea of the splendour of the electric light), it is best to purchase one of the small bars of 'gas graphite,' 15 or 20^{cm} long and a few millimetres thick, which are expressly made for the electric light, and may be had at the dealers in electrical apparatus. Two bits, each 4 or 5^{cm} long, are cut off the bar, and copper wire is coiled round one end of each of them, forming about eight or ten close turns, and leaving a straight piece of the wire to project at the end, which serves for connecting it with the wires from the battery by means of a binding screw. The copper wire should first be softened over the flame and then polished with emery-powder before coiling it round the carbon pieces. The free ends of these may be made pointed by the file; but it is quite as well to leave them as they are and bring them together by the edges, taking care to make gentle contact at one point only. As soon as the least pressure is applied, so that the surface of contact is increased and the current no longer passes through minute projecting points, a dull glow is obtained instead of a brilliant point of light.

If carbon points of the kind described cannot be obtained, two oblong pieces of dense coke may be substituted. If Bunsen elements are used, the copper wire from the zinc pole may be simply placed in contact with the carbon plate which forms the opposite pole, and a bright dot of light will appear at the point of contact.

Liquid conductors are also heated by the galvanic current. If the circuit of a battery of Bunsen's or Grove's elements is kept closed for a considerable time, the liquids in the cells are sensibly heated, especially when the connecting wires are rather short and thick.

The most remarkable action of the current upon liquid conductors is their *chemical decomposition*. All liquids which are chemically compound, and are conductors of galvanic electricity, are decomposed by it.

Chemical decomposition can only be produced with great difficulty by frictional electricity, but very easily by means of the galvanic current, because a continued action is necessary in order that the results of the decomposition may be recognisable. A discussion of these effects of the galvanic current is impossible without entering into chemical considerations; a few examples only can therefore find a place here, such cases being chosen as may help the understanding of the chemical action in the elements themselves.

The chemical decomposition of a substance by the galvanic current is termed 'Electrolysis' (from *electro*, electric, and *lysis*, a disengaging); the conductors (wires, plates, or the like), by which the current enters and leaves the substance to be decomposed, are both called 'Electrodes' (electric ways, from *hodos*, a way); the positive pole by which the current enters the substance is called the 'anode' (*ana*, up, and *hodos*); and the negative pole, where it leaves, the 'cathode' (*cata*, down, and *hodos*).

Sodic sulphate, or Glauber's salt, is one of the substances which may be very easily decomposed. It can be made from sulphuric acid and soda, and the galvanic

current decomposes it again into these two constituents. There are some blue vegetable colours which are turned red by sulphuric acid, and green by soda, while the blue is not altered at all by Glauber's salt. If a solution of Glauber's salt is coloured blue by any of these colouring matters, and two strips of platinum foil, connected with the terminals of a battery of at least two strong elements, be dipped into the solution, sulphuric acid will be given off at the strip which forms the anode, and soda at the cathode, hence the blue colour will change into red at the anode and into green at the cathode. If the electrodes are withdrawn from the liquid, and the whole well stirred, the two substances which have been separated combine again, and the blue colour is restored.

The colouring matter in most blue flowers—for example, the violet, lobelia, the common flag of our gardens (*iris germanica*), etc., is changed to red by sulphuric acid, and to green by soda. To obtain the colouring matter some of the flowers should be digested with a small quantity of warm alcohol; the alcohol is then poured off, and the flowers pressed in muslin. A blue solution is obtained, which will yield a blue pigment if gently evaporated. The blue pigment dissolves in water and may be used for giving a blue colour to the solution of Glauber's salt. An easier plan is to make a decoction of the leaves of red cabbage. A few leaves are cut up small, just covered with water, and heated until the water begins to boil. The liquid is poured off, filtered, and a little Glauber's salt dissolved in it (about 5 grammes in 50°c). The solution obtained in this way is usually rather red, but the necessary blue colouring may be given to it by the addition of a minute quantity of soda. A piece of soda of the size of a pea is dissolved in a spoonful of water, and drop after drop of it poured into the red liquid until it becomes blue. The liquid must be stirred after each drop before another is added. An excess of soda must be most carefully avoided; let the blue liquid have a violet rather than a green tinge.

The effect of the sulphuric acid and soda upon the blue colour may easily be seen by pouring a small quantity of the blue solution

into two test-tubes, and adding to one a drop or two of dilute sulphuric acid, and to the other a few drops of solution of caustic soda. The colour of the liquid in the first tube will turn to a beautiful red, in the other it will change into a bright green.

The electrodes must be formed of platinum foil, because all metals with the exception of platinum and gold are attacked by some of the products of the decomposition, and the results would thus be vitiated.

The experiment may be made on a very small scale by bending a short piece of glass tubing, 2 or 3^{mm} wide, so that both branches are parallel and nearly close together. About 6 or 10^{mm} from the bend a cut is made with the triangular file, and the portion above the cut broken off. A very small U-tube, like that in fig. 341, is thus ob-



FIG. 341 (*real size*).



FIG. 342 (*real size*).

tained, which may be supported by heating the bent part and sticking it into a square piece of sealing-wax, which serves as its foot. Two small pieces of platinum wire are connected by clamps with the terminals of the small battery in fig. 336, and dipped as far as shown in fig. 341 into the U-tube, which is filled with the blue liquid. After a few minutes the liquid at the anode becomes red, at the cathode green. If platinum wire cannot be had copper wire may be substituted; the copper is attacked by the sulphuric acid which appears at the anode, but not by the soda which is disengaged at the cathode.

A U-tube of somewhat larger dimensions is, however, preferable for the experiment. The branches should be several centimetres long, and the diameter of the tube at least 1^{cm}. It is filled with the liquid, clamped in the retort-stand, and two platinum strips, 4 or 6^{mm} wide and from 3 to 5^{cm} long, are used as electrodes. Platinum wires are soldered to the strips, and bent so that they may hang over the ends of the tube, as shown in fig. 342; the wires are connected outside with the terminals of the battery by clamps. When the liquid, after one portion has become red and another

green, is poured out of the U-tube into a little dish and stirred, the original blue colour is restored, because the soda and sulphuric acid set free by the current combine again to form sodic sulphate.

Blue vegetable colours are generally very evanescent, especially when they are exposed to light. If it is desired to keep a stock of the blue solution, it should be put in a bottle with one drop of *liquid carbolic acid* well shaken, and then corked with a tight-fitting sound cork.

Water is resolved by the galvanic current into its two constituents, hydrogen and oxygen. Both of these bodies are gases, hence they are disengaged in the form of bubbles when the electrodes are dipped in water. Pure water is, however, a bad conductor of galvanic electricity, and in order to increase its conductivity a small quantity of sulphuric acid is added to it; the sulphuric acid remains unchanged if it is sufficiently diluted with water. Both gases may be separately received and examined by means of the apparatus for decomposing water represented in fig. 343. The short neck of a glass funnel is closed by an india-rubber stopper; two platinum wires pass through the stopper, carrying platinum strips at the top, and being clamped to the brass pieces *mm* below by means of the flat heads of the screws *s*. The wires from the battery are similarly clamped by the screw heads *pp*. The funnel is nearly filled with the dilute acid, and two small tubes, *gg*, usually graduated into cubic centimetres, are quite filled with the same liquid, closed with the finger, inverted, and dipped beneath the surface of the liquid in the funnel; finally each tube is suspended by the little glass ring at the end of it to one of the small hooks fixed to the support *t*. As soon as the circuit is closed decomposition begins, and gas bubbles rise from

the surface of each electrode, which collect at the top of the tubes. The volume of gas liberated at the cathode is about double that at the anode ; the former is hydrogen, the latter oxygen. When one of the tubes is full of hydrogen, it is lifted out of the liquid and inverted, while



FIG. 343 (*an. proj.* ; $\frac{1}{2}$ real size).

a burning splinter is brought rapidly close to the mouth of the tube. The gas which escapes burns with the pale non-luminous flame peculiar to hydrogen. The second tube, after the decomposition has been allowed to go on for some time longer, is similarly removed ; it is also turned mouth upwards and a splinter of wood

red-hot at the point is introduced: it will be rekindled. This is known as a characteristic test for oxygen, for combustion, which is nothing else but combination of substances with oxygen, is much more intense in pure oxygen than in air which contains the oxygen in a diluted state, since 100 parts by volume of air contain only 21 of oxygen, the remainder being nearly all nitrogen, a gas which does not support combustion.

If the two gases produced by the decomposition of water, instead of being separately received, are allowed to mix after being disengaged, the mixture, called oxy-hydrogen gas, explodes with great violence and a loud report when a light is applied to it. For this purpose a small inverted funnel is placed over the electrodes instead of the tubes, and a narrow india-rubber tube is slipped over the end of the funnel, as shown in section in fig. 344. The end of the rubber tube is led into a small shallow dish, best of metal or wood, containing water in which some soap has been dissolved. The surface will

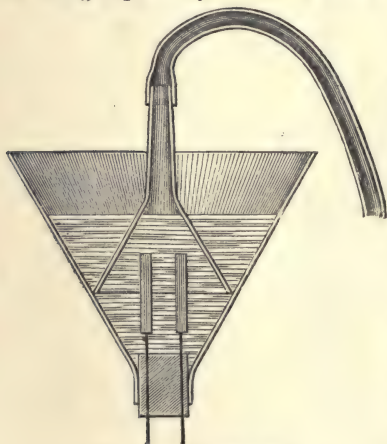


FIG. 344 ($\frac{1}{2}$ real size).

soon be covered with a little heap of bubbles, which may be lighted by a burning match, but not until after the end of the rubber tube has been withdrawn from the liquid, or otherwise the flame may be communicated through the tube to the funnel, and the apparatus shattered by the explosion. The report is very loud and sharp, the sharper the smaller the bubbles in the heap, and the bubbles are the smaller the narrower the india-rubber tube is. Small bubbles may, however, be also obtained from a wide tube, if the mouth of the tube, which dips under the liquid, be held in a horizontal position and pressed with the finger against the bottom of the dish, so that the gas escapes only through a narrow slit which remains open between the tube and the bottom of the vessel.

For the mere decomposition of water, when it is not intended or

necessary to collect the gases separately, the cheaper apparatus, represented in fig. 345 *A*, may be constructed. The platinum electrodes are replaced by strips of very thin sheet iron, which are passed through a cork, are bent as shown in the figure, and have short pieces of copper wire or strips of copper soldered to them. A bent glass tube is also inserted in the cork, which serves for conveying the oxy-hydrogen gas into the solution of soap. The strips of iron are cut in the form shown at *B* in the figure; two slits are made with the penknife through the cork, and also a hole for the glass

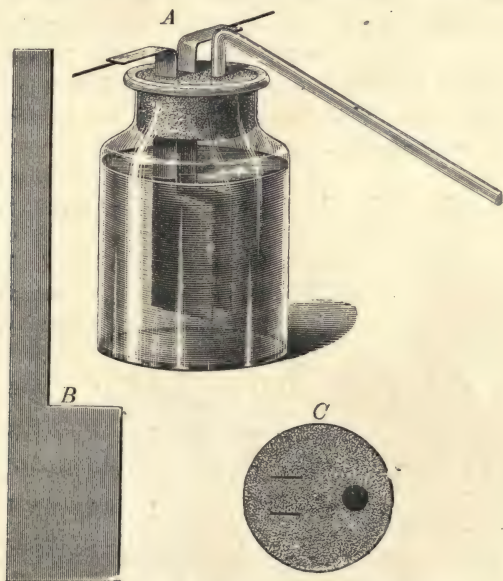


FIG. 345 (*A* an. proj., $\frac{2}{3}$ real size; *B* and *C* real size).

tube, as shown at *C* in the figure; the strips of iron are pushed through the cork from below, the copper wires or strips are soldered to them with soft solder, the strips are then bent at right angles, and finally the glass tube is set in. The little bottle (a small glass pomatum jar) is filled with a strong solution of caustic potash. This substance is sold in small sticks, which are very deliquescent when exposed to the air, as they attract the moisture and also the carbonic acid contained in the atmosphere; the sticks should therefore be dissolved very soon after they are purchased. The solution, which becomes hot at first, should contain about 10 grammes in 50^{cc} of water. It is poured into the jar by means of a funnel, care being taken not to wet the neck of the jar. The cork

is then pressed well in, and finally, with the help of the blowpipe, covered with sealing-wax, in the manner previously explained.

In handling the potash solution care should be taken that none of it drops on the hands or clothes, as it corrodes both the skin and woollen cloth. If any of it should have dropped upon the clothes, the part is first well washed with water and then moistened with vinegar, which may afterwards be also washed out.

The oxygen disengaged under these circumstances does not attack the iron electrode; although, if sulphuric acid were used instead of potash, the iron would be rapidly dissolved, just as zinc is in dilute sulphuric acid. The potash solution has the disadvantage of frothing, and hence some of it gets carried over into the dish with the soap-water; but this does not in any way interfere with the success of the experiment. The cork is also attacked strongly by the potash and gradually destroyed; it must therefore be renewed from time to time.

The little glass tube should dip into the soap-water, no india-rubber tubing being required; it must of course be removed, with the whole apparatus, before the oxy-hydrogen bubbles are lighted.

Persons with sensitive ears should open their mouths when the match is applied to the bubbles; the sound will then have less effect upon the ear.

In the decomposition by the galvanic current of the compounds of the heavy metals (gold, silver, copper, etc.), the metal is always disengaged at the cathode, while the substance or compound combined with the metal is set free at the anode. Thus if a current passes through an aqueous solution of cupric sulphate (blue vitriol, see page 215), the cathode is soon covered with a bright layer of pure copper, while the sulphuric acid which was in combination with the copper is disengaged at the anode.

The platinum strips used for the decomposition of sodic sulphate are used as electrodes in this experiment also. They are dipped into a small jar or beaker, which contains the cupric sulphate solution, and are kept about 1 or 2^{cm} apart. The red copper deposit upon the cathode cannot be seen until the platinum strip is taken out of the blue liquid. When an appreciable layer of copper has been deposited the electrodes are interchanged, that is, the cathode

is made the anode, and *vice versa*. The copper is now deposited upon the new cathode, while the sulphuric acid, now disengaged at the new anode, dissolves the previously deposited copper; this copper, therefore, gradually disappears again.

A solution of 3 grammes cupric sulphate in about 30^{cc} water, the same as made previously (page 215), is available also for the galvanic decomposition. The current from two Grove or Bunsen elements has the most suitable strength for this experiment; if the current is weaker it takes too long a time before a copper deposit appears; and again, if the current is considerably stronger the copper is deposited upon the platinum as a dark red and even black powder instead of as a uniform brilliant coating.

The electrode which is covered with copper after the experiment should be dipped into a test-tube and a little nitric acid poured over it; the copper is very soon dissolved, and afterwards the platinum should be washed with a little water.

These decompositions, of solution of sodic and cupric sulphate and of acidulated water, prove that when a compound in the liquid state forms part of a closed galvanic circuit, chemical changes are produced in the liquid by the action of the current, and we may conclude that in the liquids of the elements themselves similar decompositions must be effected by the current. The diagram, fig. 346, represents a battery of three copper and zinc elements, the liquid being acidulated water. K_1, K_2, K_3 , are the three copper plates, Z_1, Z_2, Z_3 , the three zinc plates; K_1 is the positive pole of the battery, Z_3 the negative pole, and from the poles wires pass to the electrodes, p_1 and p_2 , which are immersed in acidulated water. The (positive) current flows from K_1 to p_1 , through the water to p_2 , and thence to Z_3 ; it therefore enters the water through p_1 , and leaves it through p_2 ; and p_1 , which is connected with the copper, is the anode, while p_2 , which is connected with the zinc, is the cathode. Thus at p_1 oxygen is disengaged, and at p_2 hydrogen.

In each element, the current clearly enters the liquid by the zinc plate and leaves it by the copper plate ; consequently the zinc plate is the anode and the copper plate the cathode ; the oxygen therefore appears within each cell at the zinc plate, and the hydrogen at the copper plate. It has already been stated that the direc-

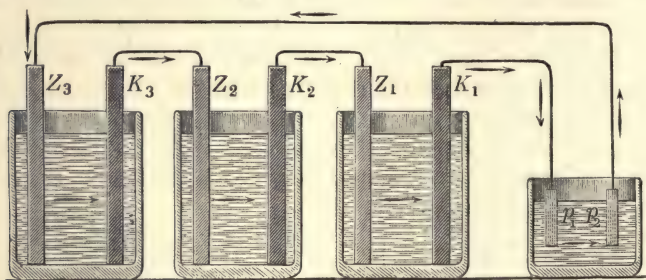


FIG. 346.

tion of the current within the liquid of the cell is from the zinc to the copper, and a glance at the direction of the arrows in fig. 346 will render the fact still more obvious.

The oxygen which is thus separated at the zinc plate does not escape in bubbles, for it combines chemically with a portion of the zinc to 'zinc oxide,' which either becomes visible as fine white flakes, as may be seen after using the small battery for some time, fig. 336, or is dissolved in the liquid when acid is present in the water. It is thus that the zinc is 'consumed,' as has been mentioned previously.

The action of the hydrogen which is disengaged at the copper plate,—or at the platinum and carbon, if either of these substances is substituted for the copper in a battery arranged as those in fig. 346, or fig. 336, is very different. A part of the hydrogen set free by

the action of the current escapes in the form of bubbles, but another part is gradually condensed upon the copper, platinum, or carbon respectively, as an invisible fine layer, which covers the entire surface of the plate. It follows that the points of contact of plate and liquid are more and more reduced, and that hence the quantity of electricity produced becomes gradually less. Moreover, the film of hydrogen thus formed acts precisely like a metal with reference to the liquid which is interposed between it and the zinc, an electromotive force begins to act, which is not only perfectly independent of that previously called into play by the two metals and the liquid, but which tends to generate a current opposite in direction to that produced by the battery. The result is that the current is rapidly enfeebled and that batteries arranged like those represented in figures 336 and 346 only act energetically during the first few moments after the circuit is closed.

The deposition of hydrogen on the surface of the plate which forms the positive pole must consequently be prevented by some means if a constant current is to be obtained. Elements in which this is effected are called 'constant' elements. They generally contain two liquids, or in a few rare cases they contain besides the two plates which form the poles, one liquid and one solid, the latter of which covers the positive plate and is acted on chemically while the current exists. Bunsen's and Grove's elements are constant; in either of them the hydrogen which is produced decomposes the nitric acid in the porous cell, and the products of the decomposition are water and nitrous acid, the latter of which does not interfere with the action of the elements.

Nitric acid, however, cannot be used in copper-zinc elements for preventing the deposition of hydrogen, because copper is strongly attacked by nitric acid and rapidly dissolved. Constant elements with plates of copper and zinc may be constructed by placing the copper plate in a solution of cupric sulphate. It has already been shown that the action of the current upon a solution of cupric sulphate is to deposit the copper upon the cathode, and since within such an element the copper plate forms the cathode, it gradually becomes thicker by receiving new deposits of the metal of which it consists, and its action therefore remains unchanged. This action was taken advantage of by Daniell in the construction of the first form of a constant element which came into use, known as *Daniell's cell*, and represented in fig. 347. V is a glass or porcelain vessel containing a saturated solution of cupric sulphate, in which is immersed a copper cylinder, C, open at both ends and perforated by holes. At the upper part of this cylinder there is an annular shelf, G,



FIG. 347.

also perforated by small holes, and below the upper surface of the solution. The shelf is intended to support crystals of cupric sulphate to replace that decomposed as the electrical action proceeds. Inside the cylinder is a thin porous vessel, P, of unglazed earthenware, which contains either salt water or dilute sulphuric acid, in which is placed the cylinder of amalgamated zinc, Z. Two thin strips of copper, p and

n , fixed by binding screws to the copper and to the zinc, serve for connecting the elements in series.

In this cell the hydrogen which is disengaged simply replaces the copper which is deposited upon the positive plate in consequence of the decomposition of the copper sulphate, the result of this substitution being hydrogen sulphate, that is, sulphuric acid. This sulphuric acid tends to replace that used up by the zinc, while the crystals of cupric sulphate on the shelf keep the solution of cupric sulphate, which obviously would otherwise become weaker by the decomposition that is going on, in a saturated state.

The use of the porous vessel is attended in all batteries with some inconvenience, and especially so in Daniell's battery, in consequence of an incrustation of copper which is gradually formed upon the clay, and renders the vessel useless. Batteries have therefore been devised in which the porous vessel is entirely dispensed with, and the separation of the liquids effected by their difference of density. Such batteries are called *gravity batteries*. A single cell of this kind, being a modification of Daniell's combination by Meidinger, and known by the name of *Meidinger's balloon element*, is represented in section in fig. 348 *A*.

The glass vessel $g g$, of which the upper portion is wider than the lower, contains a thin cylinder of copper, k , and also one of zinc, $z z$, which either rests on the shoulder formed by the junction of the narrower part with the wider, as in the figure, or is suspended from the edge of the glass vessel by three small projections which are bent outwards and fit into three corresponding incisions of the edge of the glass. The zinc is immersed in this cell in a solution of magnesian sulphate (Epsom salt) in water, and the copper cylinder in cupric sulphate; this being heavier than the magnesian sulphate fills the lower part of the vessel, and is therefore in contact with the copper cylinder, while the magnesian sulphate, which is lighter, remains in the upper part of the vessel round the zinc cylinder. The shelf in Daniell's cell is replaced by the balloon b , which contains a store of crystals of cupric sulphate, by which the solution, which without it would gradually become weakened, is constantly kept saturated. In charging the cell the glass $g g$ is filled to about

two-thirds with a solution containing 140 grammes of commercial Epsom salt in one litre of water. The balloon being placed mouth upwards upon some hollow vessel, such as a pot or pan, in order to keep it steady, is filled with solid crystals of cupric sulphate, about as large as a pea or a hazel nut, and then some of the solution of Epsom salt is poured in until it is quite full, the liquid also filling the interstices between the crystals. The mouth of the balloon is then closed by the cork carrying the tube *r*, and the balloon being inverted it is placed upon the cell. The narrow tube *r* prevents the entrance of air into the balloon while it is inverted, and consequently the discharge of any of the liquid; it serves also to prolong the neck of the bottle, as it is desirable that the mouth should be at about the middle of the copper cylinder.

When the balloon is inverted, the liquid in it, which already contains some magnesian sulphate, dissolves a further quantity of cupric sulphate, and becomes thereby heavier than the solution of magnesian sulphate contained in the glass vessel *g g*. Hence an opposite flow of liquids takes place through the tube *r*: the heavier liquid which contains some cupric sulphate descends, while the magnesian sulphate solution ascends into the balloon. The lighter solution which has thus entered again dissolves some cupric sulphate and descends in its turn, making room for lighter liquid; and it is clear that this interchange of liquids will continue until there is only a completely saturated solution of cupric sulphate from the bottom of the cell up to the mouth of the balloon. This state of matters is well shown in the section of another form of Meidinger's cell, fig. 348 *B*, which differs from a balloon element only in this, that the balloon is replaced by the cylindrical vessel *D*, which is supported by the lid *E* by which the cell is covered. Further, the tube *r* is replaced by a small aperture in the bottom of the vessel *D*, and the copper cylinder does not stand free in the cell, but in a slightly conical glass vessel *B*, which is cemented to the bottom of the cell. As soon as there is a concentrated solution of cupric sulphate below the aperture of the vessel which contains the crystals, the upward and downward flow ceases; but as the current decomposes some of the cupric sulphate, and tends to render the solution weaker, its strength is maintained by the descent of heavier liquid from the balloon in *A* or the glass vessel in *B*.

Copper wires are fixed to the copper and the zinc in the cell, which serve as terminals or for connecting several cells; the wire which leads from the copper is insulated where it passes through the liquid by a glass tube or a covering of gutta-percha. The balloon has generally two grooves in the glass, on opposite sides,

which permit the passage of the wires between the balloon and the rim of the cell.

The current produced by Meidinger's elements is so feeble that it cannot be used at all for experiments on heating effects, and is insufficient for effecting chemical decompositions with rapidity. The batteries are, however, very serviceable where a weak but very constant current is required, as in electric telegraphy, and for similar

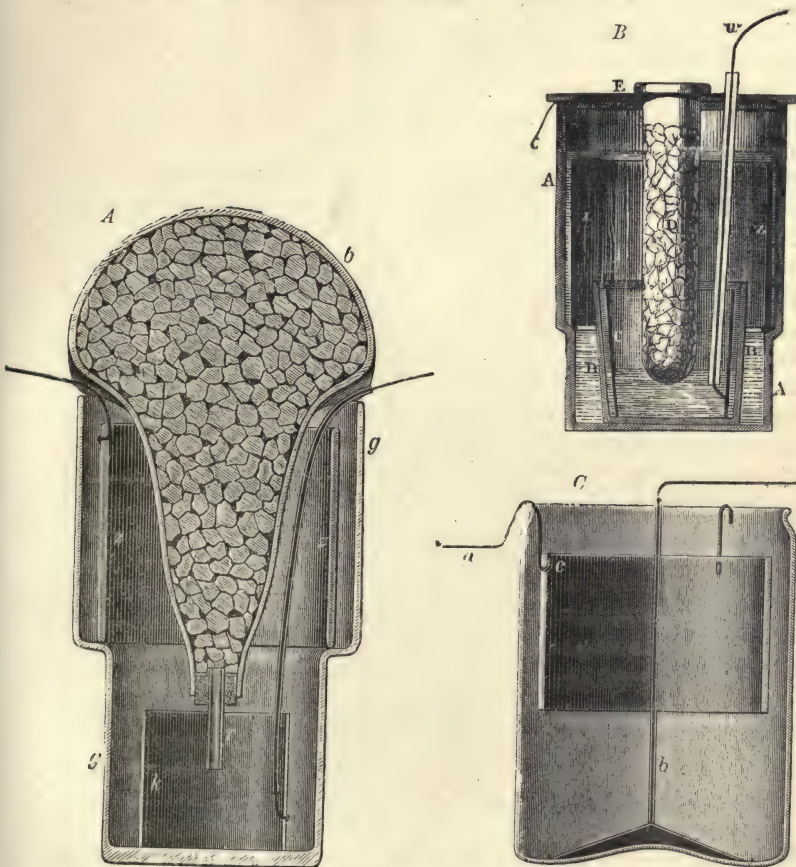


FIG. 348 (*A* and *C* $\frac{1}{2}$ real size; *B* $\frac{1}{4}$ real size).

purposes, which will be described farther on. When the circuit is uninterruptedly closed, such elements give a constant current for one or two months; if the circuit is only occasionally closed, as for electric bells etc., they will even act for a year or two.

The balloon should never be placed upon the cell unless the latter

is in the place where it is to remain afterwards; if balloon and cell together are carried about from place to place, the liquids will inevitably mix, and the action of the cell is disturbed. If possible the battery should be kept in a room in which no fire is lit, and in which the temperature does not change very rapidly. If the elements are allowed to stand unused, some of the solution of cupric sulphate rises in consequence of diffusion (see page 215), and reaches the zinc cylinder. Zinc decomposes the copper sulphate, zinc sulphate and copper being formed, the latter being deposited as a soft brownish-black mass, which interferes with the action of the cell when it is to be used. But if the current is closed, either permanently, or at least from time to time, the ascent of the solution of cupric sulphate is prevented by the action of the current which constantly carries it to the cathode, that is, downwards to the copper. A battery of Meidinger elements should therefore, if not in use, be closed from time to time for a few hours.

Fig. 349 *C* represents in section a modification of a Meidinger element which the student may construct for himself. Procure a suitable glass jar, and let a tinsmith make you a cylinder of zinc, 2 or 3^{mm} thick, about 1^{cm} less in width than your jar, and about half as high. Drill three holes into the cylinder, near the edge, at equal distances from one another, and each about 1.5 or 2^{mm} wide. The cylinder is suspended in the jar by means of three stout pieces of brass or copper wire, which are softened in the flame; each is pushed through a hole, bent at one end as shown at *c*, and soldered to the cylinder. One of the wires is to serve as a terminal, or for making connection, in addition to holding the cylinder suspended; it should therefore be made longer than the others, as shown at *a* in fig. 348 *C*. The zinc is amalgamated after the wires are fixed. The copper is introduced as a circular disc of sheet copper, 2 or 3^{cm} less in diameter than the mouth of the jar. If the bottom of the jar is not flat, a cut is made into the disc of copper from the edge to the centre, and the cut edges are made to overlap one another, so that the whole forms a flat cone as shown in the figure. The end of a copper wire, *b*, is soldered to the middle of the copper disc, and after washing away any residue of the soldering fluid, the wire is heated, and the part of it which is inside the jar when the wire stands perpendicular is covered all round with sealing-wax. The portion not covered with sealing-wax is bent horizontal. The metal pieces being placed in the jar, it is filled with solution of magnesian sulphate, and a handful of crystals of cupric sulphate is thrown into it, which dissolves and forms a deep blue saturated solution at the bottom of the jar. When after the cell has been in use for some

time the deep blue colour changes into a lighter blue, a few more crystals must be added.

A battery of Meidinger elements when first put together should be left to stand for a few hours with closed circuit, before making use of it, for its action is extremely feeble at first.

When the battery after long use ceases to act, it should be taken to pieces. The zinc is then generally found to be so thin and full of holes that it crumbles during the attempt to clean it. But if, after scraping off the impurities which are usually found deposited upon it, a pretty firm cylinder of zinc is left, it ought to be well cleaned with a hard brush, and used once more after amalgamating it again if necessary. At the bottom of the vessel a quantity of copper is found, partly as a brown soft sediment, partly as a dense bright red deposit upon the copper plate, the latter of which may be removed by bending the copper plate to and fro. The greater part of the deposit will peel off, and after scraping off the remainder as completely as possible, the copper is bent into its original form. The soft sediment is of course poured into a vessel if, as is the case in large electric telegraph establishments, it is intended to sell the copper residues. They repay in such cases the outlay for the cupric sulphate, but where the batteries are used on a small scale as in a laboratory, the sale of the copper residues is scarcely feasible. In taking the cells to pieces the two liquids cannot be prevented from mixing, hence the cells must be refilled with a fresh solution of Epsom salt.

The copper cylinder is sometimes, especially in Meidinger elements sold by dealers, replaced by a cylinder of lead. The action of lead in a galvanic cell is less energetic than that of copper, and hence such cells produce at first a very feeble current; but as copper is very soon deposited on the lead, the action is afterwards the same as if the whole cylinder were made of copper, while on the other hand the leaden cylinders are more easily bent than those of copper, and the removal of the deposited copper is therefore easier.

The precipitation of metals from solutions by the action of the galvanic current has received many important practical applications. If the precipitation proceeds sufficiently slowly a dense coherent layer of metal is formed, which adapts itself exactly to the external surface of the cathode, and under certain circumstances adheres to it very firmly. Thus if a conductor is im-

mersed as cathode into a solution of a cyanide of gold or silver, the conductor is covered with a film of gold or silver respectively, which, with certain suitable precautions, may be made to adhere as firmly as the film of gold or silver produced upon bodies by the older methods of gilding or silvering.

The layer of copper which has been precipitated upon a cathode immersed in solution of cupric sulphate may be removed after it has become sufficiently thick, and forms then a more beautiful and faithful impression of the original than can be obtained by any other means. Those portions of the surface of the cathode which are raised of course appear hollow in the cast, and *vice versâ*; but if the first cast be used itself as cathode a second cast is obtained, which is in every respect a most faithful copy of the original. These facts form the basis of the arts called *electro-metallurgy* or *galvano-plastics*. It is thus that copper plates and woodcuts are multiplied. An engraved copper plate or block of wood can only be used for a certain number of impressions, because the soft surface of the copper or wood is soon worn away; but by employing the galvanic current in the manner above indicated a great number of casts may at once be obtained from the original plate or block, and these may be used like the original for producing good impressions on paper to any extent.

A galvano-plastic copy of a coin may be very easily produced. It is, however, best to make first a hollow cast of the coin in stearine, for the removal of the firmly adhering deposit from the original is often very difficult and can scarcely be accomplished without damaging it. The cast taken from the stearine is moreover at once in relief like the original coin.

A somewhat large coin (a crown piece or a florin) is well cleaned with a brush and soap and water. Being placed upon a table, a strip of paper, 2^{cm} wide and 20^{cm} long, is very tightly wrapped round the edge of the coin and gummed at the end. Into this little vessel some stearine which has been melted in a ladle is poured so as to form a layer above the coin 5 or 6^{mm} thick. If the paper was not drawn very tight round the edge, some stearine will flow through the interstices; as this can be seen at once, the trouble of having to make a new paper rim may be avoided by allowing the first small portion poured in to become solid, it will then close up all interstices, and the remainder of the stearine may after a little while be poured in safely. After an hour or so the paper rim is torn away, and the cast will mostly come off at the same time; if not it must be taken off with care, so as neither to break it nor to produce scratches.

Stearine is a non-conductor; it must therefore be covered with a conducting substance before it can be used as cathode. This is done by 'black-leading' it. Black-lead is an inferior sort of graphite, one of the forms in which carbon occurs in nature. Graphite is a soft variety of carbon, generally of a laminated structure, which is found in mines; the better kinds are used for pencils, the inferior kinds for giving a black polish to iron articles, such as stoves, etc., and as it is nearly incombustible, crucibles are also made of it, which stand the strongest heat without burning. A little black-lead is rubbed down in a mortar to as fine a powder as possible until it no longer feels gritty. To make it still finer it should be sifted through a piece of fine linen or cotton. The powder is shaken from the mortar upon a square piece of the fabric, 10 or 12^{cm} long each way; the corners are then taken up, joined, and tied with thread, and the little bag formed in this way is knocked against a flat horizontal board until a sufficient quantity has passed through the meshes of the fabric. The black-lead is first rubbed upon the edge of the stearine cast with the point of the finger, and is then applied to the surface which represents the hollow copy of the coin by means of a soft camel's-hair brush.

A thin copper wire, made very soft in the flame and then rubbed bright again, must be laid round the edge of

the cast and fastened by cautiously twisting it, as in fig. 349. The end of this wire may now be connected with the negative pole of a weak battery, and the cast be immersed in a saturated solution of



FIG. 349 (an *proj.*; real size).

cupric sulphate into which a copper plate dips which is connected with the positive pole and forms the anode.

The process may be still further simplified if the deposition of copper which takes place in a galvanic cell containing cupric sulphate is used directly for the production of the galvano-plastic copy. Graphite behaves nearly like copper in a galvanic cell, and the stearine cast covered with black-lead may therefore be at once substituted for the copper in a cell of the form shown in fig. 348 C.

The perpendicular portion of the wire attached to the stearine cast should be varnished with 'black japan' before putting it into the cell, this will prevent the deposition of copper upon it; the upper extremity is clamped to the connecting wire of the zinc cylinder by a binding screw. The magnesian sulphate solution should for this experiment be much weaker than that previously used, so as to possess less conductivity, for the current must be very feeble; as much of the solid salt as can be taken up with the point of a knife is quite sufficient for the whole cell. The crystals of the cupric sulphate must in this case not be *thrown* into the vessel but cautiously placed all round the stearine cast, using the crucible tongs for the operation. The dark blue solution must stand at least a few millimetres above the stearine. After from three to eight days, during which time the used crystals must be replaced now and then by others, the deposit will be thick enough to be taken off. Any bits of copper deposited round the lower surface of the stearine are first cautiously broken away, and the copper deposit on the upper surface is then raised; if this cannot be done the stearine is melted off. In order to give the copy a neat appearance the adhering edge must be removed. For this purpose the inner side or reverse of the copy is moistened with soldering liquid, a little solder placed upon it, and heated until it flows and spreads over the whole surface. The copper deposited by the current is very brittle, and even when very thick and substantial in appearance the file cannot be applied to it for removing the edge, but the back of solder will render it firm enough for using the file for the purpose.

Casts often have small holes, and if there are any the melted solder would clearly run through them and spoil the whole. These holes are caused by air bubbles which adhere to the surface of the stearine when the latter is introduced into the cell. It is therefore advisable to remove at once all visible bubbles with a pointed camel's-hair brush, taking care, however, not to brush too hard along the surface, otherwise portions of the thin conducting layer might be removed altogether.

After the edge has been removed the face of the copy may be polished with a small brush dipped into a little 'whitening,' which has been rubbed to a soft pulp with a few drops of spirit of wine.

Whitening (or 'Spanish white') is sold by oil and colourmen.

50. *Action of galvanic currents upon each other. Ampère's laws.*—Two conductors traversed by galvanic currents exert a mutual action upon each other which depends on the relative position of the conductors and the direction of the currents. In order to observe the effects produced by this mutual action, one at least of the conductors must be easily movable. If a fixed conductor, through which a current passes, be brought into the vicinity of such a movable conductor, which is parallel to the first and is traversed by a current which flows in the same direction, attraction takes place, and the movable conductor approaches to the fixed. But if the current in the first conductor flows in a direction opposite to that of the current in the movable conductor, repulsion takes place, and the movable conductor recedes from the fixed. Finally, if the currents cross each other, the movable conductor turns about its axis of motion until it is parallel to the fixed and both currents flow in the same direction.

The laws which regulate these effects of currents upon each other, are called *Ampère's laws*, and may be enunciated thus:—

I. *Two parallel currents in the same direction attract one another.*

II. *Two parallel currents in contrary directions repel one another.*

III. *Two intersecting currents tend to become parallel and to be in the same direction.*

The last of these laws may be stated somewhat differently. Let ab and cd in fig. 350 represent two currents flowing in directions indicated by the points of the arrows. The conductors tend to move until a coincides with c and b with d , in other words, attraction takes place between the portions ae and ce , and also between eb and ed ,



FIG. 350.

while repulsion takes place between ae and ed , and ce and eb . Now in ae and ce , the currents flow *towards* the point of intersection e , in eb and ed they flow *from* the point of intersection. Hence we may express the third law by two statements:—

A. Two currents, the directions of which intersect, attract one another when both flow towards or away from the point of intersection.

B. They repel one another if one flows towards the point of intersection and the other away from it.

When strong currents can be used for the experiments, a simple conductor, suspended so that it can move freely, and a second conductor, also simple, which can be brought near the other, are quite sufficient for manifesting appreciable movements. But with a current from two Bunsen or Grove elements it is best to employ conductors which consist of several insulated copper wires placed side by side in such a manner that the current has the same direction in all those parts of the conductor which adjoin. In an arrangement of this kind the effect becomes multiplied, for we have not the action of a single current upon another single current, but that of several upon several.

Upon a small board, fig. 351 *A*, a square is drawn, each side being 15^{cm} long. Wire tacks are driven in at each of the corners a , b , c , d , and also at the points e and f . A piece of covered copper wire, 3^m.3 or a little more in length and from 0.6 to 1^{mm} thick (without the covering), is fastened by one end to the tack f , and drawn **very** tight round a to b , c , d , and then five times round the square; the end of the wire is fixed by twisting it several times

round the tack *e*. There will now be four turns of wire in the side *ad* of the square, and five turns in every other side of it. Thread a needle with a long thread and pass it exactly at the middle of *ad* under the four turns of wire, and also under the piece of wire between *d* and *e* (not under that between *a* and *f*), make a loop at the end of the thread, draw it tightly round the wires, and tie the whole together with a double knot. One-half of the piece of wire from *d* to *e*, viz., that on the right, will in this way be drawn close to the other four wires, as represented in fig. 351 *A*. The thread is then wrapped spirally round all the wires, proceeding along the sides of the square, pushing the needle at each turn underneath the wires, taking care at the corners not to tie tacks and wires together,

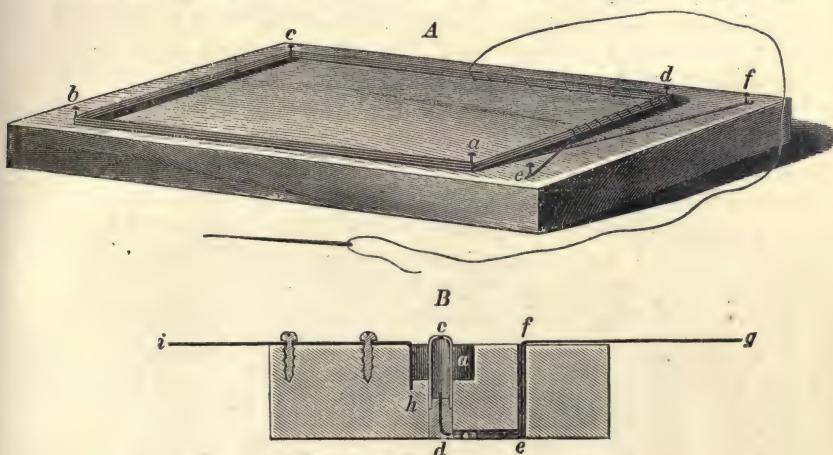


FIG. 351 (*A* an. proj., $\frac{2}{3}$ real size; *B* $\frac{1}{2}$ real size).

but to carry the thread only underneath the wires and round them, leaving the tacks quite free. The figure shows the square when the thread has been wrapped round one-fourth of the whole. When arrived at *a* the thread is drawn also round the piece of wire *af*, so that this is made to join the four turns between *a* and *d*, and the whole is ended about 6^{mm} before reaching the middle of *ad*, where the work commenced. The thread is firmly tied at that point, the ends of the wires are cut close to *e* and *f* with the nippers, and the tacks *a*, *b*, and *c* are drawn out of the board to set the square free. The ends of the wire are held for a short time in a flame to burn away the covering; they are then neatly polished with emery-paper, and after straightening the sides of the square where necessary, so that it may form a correct square with straight sides and right angles, the free ends are bent so as to be parallel to the sides

a b and *c d* of the square, one projecting from the middle of the side *a b*, the other end being parallel to the first, at a distance of 6^{mm} from it. To the middle of the side *b c* a small ring and hook of covered wire is attached, the construction of which will be rendered sufficiently clear from fig. 352 *A*, which shows the square when completed.

A second square is also made in the same way, having five turns of wire, but having each side only 11^{cm} long. In making it, the tack *e* is driven into the board a little more to the left, and the tack *f* a little more to the right, so that the free ends may be somewhat longer. The distance between the two parallel ends should in this square be 12^{mm}; the binding of the wires with thread should therefore be commenced not in the middle, but 6^{mm} from the middle, and end 6^{mm} from it. These two ends must be bent so as to be horizontal when the square is held vertical. The square itself is fixed with sealing-wax to one end of a strip of wood 10^{cm} long, 1^{cm} wide, and 5^{mm} thick. Two holes are made through the wood with a red-hot wire, and each of the wire ends is drawn through one of them as shown in fig. 352.

The larger square is suspended from the frame represented in fig. 35 (page 36) by means of a thread, to the end of which the S-shaped hook is tied, which passes through the ring attached to the square. The other end of the thread is passed first through a small hook screwed into the middle of the cross-bar of the frame, and then tied several times round a small tack driven into one of the uprights. The ends of the wire are immersed in mercury, which allows the current to enter at one end and to pass out again at the other.

In the middle of a small block of wood, fig. 351 *B*, about 10^{cm} square, and 2 or 2^{cm}.5 thick, a hole is bored with the centrebit, 8 or 10^{cm} deep and 18^{mm} wide. In the middle of this hole a smaller one is bored right through with a stout gimlet. A piece of glass tubing, 5 or 6^{mm} wide, is heated at one end in the spirit or gas flame until by the softening of the edges the bore has contracted so far that the wire used in the preparation of the squares will just pass through without friction, but not loosely. When the tube has cooled, a cut is made with the three-square file 2^{cm} from the end, and this length broken off. A piece of copper wire, 5^{cm} long and 1^{mm} thick, is surrounded near one end with a small collar of sealing-wax, and cemented into the wider end of the little glass tube in the manner explained on page 637. The little tube is then inserted from below into the hole bored in the wood, as shown in fig. 351 *B*; if necessary the hole must be widened with the rat-tail. If the tube fits tight in the hole no further cementing is required; other-

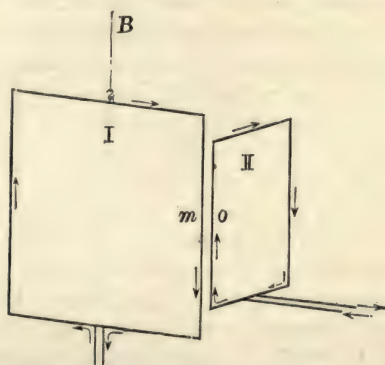
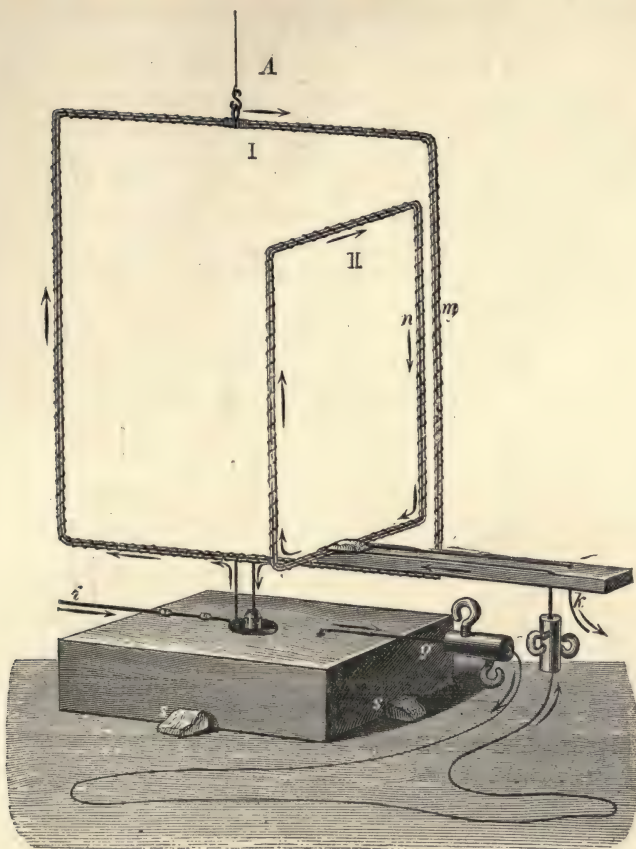


FIG. 352 A, B (*A* and *B* an. proj.; *A* $\frac{2}{3}$ real size, *B* $\frac{1}{3}$ real size).

wise the lower portion of the hole may be filled up with sealing-wax, the copper wire having been bent aside previously. A small groove should be cut for the wire in the lower surface of the wood from to *e*; at *e* a hole is bored with the gimlet, through which the wire passes upwards. The wire is placed in the groove, the end drawn through the hole *ef*, pulled pretty tight, and the piece *fg* finally bent as in the figure. At *h*, close to the side of the wider hole *a* made by the centrebit, the end of a copper wire, 1^{mm} thick, is stuck into the wood, bent at right angles at the edge of the hole and fastened along the upper surface by twisting it round two wood screws fixed in the wood.

The various parts being thus prepared they are put together in the following manner. The small glass tube *c* is filled with mercury by means of a small pipette made of a piece of glass tubing drawn

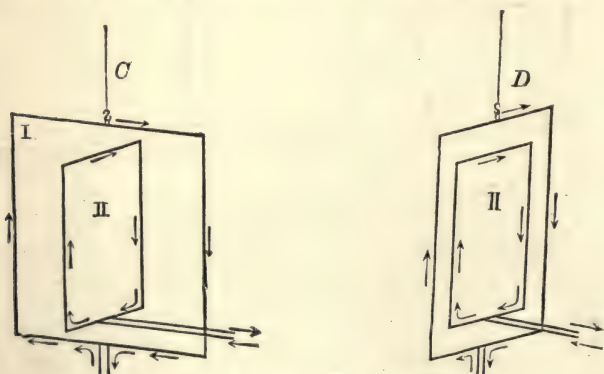


FIG. 352 C, D (*an. proj.*, $\frac{1}{8}$ real size).

to a point; the mercury should reach to within 2 or 3^{mm} from the top. The small board with the tube is then placed upon the foot of the frame, underneath the larger square suspended to the frame, and moved until the aperture of the tube is exactly below the end of that wire which projects from the *middle* of the side of the square. The end of the wire should be quite close to the aperture of the glass tube; the height at which the square is kept suspended must accordingly be adjusted by raising or lowering the thread which holds it. When the proper position of the small board has been found it is secured in its place by a few drops of sealing-wax which are allowed to fall upon the sides of the board and also upon the foot of the frame, as seen at *s, s*, fig. 352 A. Mercury is then poured into the cavity *a*, and the square is lowered until both ends of the wire dip into mercury, without however touching the

bottom of the vessels which contain it. When the ends g and i are now connected with the poles of a battery, the current can traverse the whole length of wire of which the square is formed, while the conductor itself can rotate easily. The narrowness of the small opening of the glass tube is necessary to keep the end of the wire which hangs within it in the middle of the mercury; if the tube were not contracted at the top, the wire would always press against the side and the frame would not move easily.

The smaller square which is held by the wooden strip in the hand, may be connected with another battery if a sufficient number of elements are at disposal; or, more simply, one battery only (of at least two cells) is used, and one of its terminals is connected with the wire i , fig. 352 *A*, the other with the wire k of the smaller square, while the other free wire of this square is connected with the wire g by a wire about 0^m.5 long. In the figure the wire i is supposed to be connected with the positive pole of the battery.

When the movable conductor *I* is brought near to the fixed conductor *II*, as in fig. 352 *A*, both being traversed by the current in the direction of the arrows, it will be distinctly seen that attraction takes place between the vertical sides near to one another; the square *I* begins to rotate so that the side m approaches the side n .

When the conductor *II* is held, as at *B* in fig. 352, in a position in which the sides m and o , which are near each other, are traversed by currents in opposite directions, m is repelled by o .

Finally, if one square is placed so within the other that their planes are at right angles to one another, as at *C* in the figure, *I* will rotate until both squares have the position shown at *D*. In this case portions of the current intersect in the horizontal sides of the square, and the action takes place in accordance with the previous law of intersecting currents; but it must not be overlooked that in our arrangement the effect is also partly due to the vertical portions of the current which

are parallel and in the same direction, and therefore attract each other. Arrangements for exhibiting exclusively the mutual effect of intersecting currents are rather complicated.

When the current is only permitted to traverse the movable conductor, or the fixed conductor is so far removed from it that it cannot exert any sensible influence, a further phenomenon may be observed, which will be explained further on, in the article on magnetism. The square will begin to move as soon as it is traversed by the current, and place itself in a fixed position, with its plane passing nearly from east to west, or more exactly east-north-east to west-south-west, so that the current ascends on the western side of the square and descends on the side turned towards the east.

C. Electro-magnetism. Magnetism. Induction by Currents.

51. *Electro-magnetism.*—An insulated copper wire is coiled round a glass tube in close turns, forming two or more layers of wire, and covering a little more than half the length of the tube, as shown in fig. 353. A

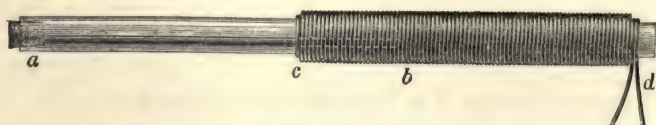


FIG. 353 (*real size*).

small bar of iron, somewhat longer than the uncovered part of the tube, which is closed at the end by a cork, is placed within the tube, the end *a* being in contact with the cork and the end *b* reaching to some distance within the coil. When a strong current is sent through

the wire the iron bar is drawn completely within the coils, the end *b* being now at *d*, the end *a* at *c*. When the current is strong enough this motion takes place not only when the glass rod is in a horizontal position, as in the figure, but also when it is held vertical, so that in that case the iron bar moves vertically upwards.

This attraction between a current which traverses a spirally coiled wire and a piece of iron lasts only as long as the current traverses the spiral; when the current is stopped the bar of iron drops if the tube be held vertical.

The iron bar itself, while the current passes round it, acquires properties similar to those which are manifested by the spiral. It becomes likewise capable of attracting iron. If a bar of iron smaller than the one in the glass tube is placed in contact with the end which projects from the tube, as in fig. 354, it is attracted and supported by it, and the small bar can support a second one, and this perhaps a third. In this case as in the former all manifestation of attraction ceases immediately on interrupting the current; as soon as it ceases the bar in contact with the one in the tube is released, the other bars separate, and fall down in obedience to the force of gravity.

Phenomena of this kind are explained by assuming that a closed electric current is constantly passing round each individual molecule of the iron, and that these infinitely small currents (called *Ampèrian currents* after the physicist who first proposed this explanation) have under ordinary circumstances all possible directions; in



FIG. 354
(real size).

other words, the small current round one molecule may be parallel to that round another, at right angles to that round a third molecule, and so on, so that there are on the average as many currents in one direction as there are in any other. The obvious consequence of this is that the total action of all these currents upon any external substance is nothing, because the effect which might be produced by one set of currents having a given direction is precisely neutralised by another set flowing in the opposite direction. Further, it is assumed that the position of these small circuits is by no means fixed, but that under the influence of a strong current which flows near them they may take up new positions.

Now the action of a fixed current upon a movable one is, in accordance with Ampère's laws, to make both currents parallel and their directions the same. The same action must be produced in a system of movable molecular currents by a galvanic current in their vicinity. Each successive coil of the spiral through which it passes represents nearly a circular closed current, and gives to the molecular currents in its neighbourhood a position parallel to itself and a direction like its own. But currents which are parallel and in the same direction attract one another; hence the bar is attracted by the spiral, and drawn into the interior of the latter as far as possible. Moreover, as soon as the molecular currents have changed their irregular positions to one of parallelism, they are capable of acting exactly like the system of parallel currents in the spiral, that is, they are capable of causing the molecular currents in another piece of iron to become parallel and assume a like direction; there will thus be mutual attraction produced

between the first bar and the second, between this and a third, and so on.

A piece of iron in which the molecular currents flow in parallel and like directions, and which thus acquires the property of attracting other pieces of iron, is called *magnetic*. Every other piece of iron brought in contact with one which is magnetic becomes also magnetic, but the number of pieces which may be thus attracted and supported, in the manner of fig. 354, very soon reaches a limit. The reason is that although the Ampèrian currents in soft iron are easily rendered parallel by the influence of a strong current, such as passes through the spiral or a magnetic piece of iron, yet they quite as easily return to their original irregular positions and always tend to do so; hence it requires a very strong influence to produce perfect parallelism of all molecular currents and to maintain it, that is, to make the iron perfectly magnetic. This strong influence is exerted upon the first bar by the current in the spiral, if it is sufficiently intense; the 'magnetisation' of this bar may therefore possibly be complete. But this bar cannot exert the same influence upon the second, because only a very small portion of the second bar is in close vicinity to the first, while the remainder is at some distance from it, and the influence is weakened by distance. For the same reason the parallelism in the third piece is still less complete than that in the second; hence its magnetism is still less perfect, and so on.

The facility with which in soft iron the Ampèrian currents return to their original irregular positions explains why soft iron cannot become *permanently* magnetic; it assumes the magnetic state only *temporarily*

while under the influence of a current or another piece of iron which is magnetic. In the former case, when the iron becomes magnetic under the influence of an electric current, it is called an *electro-magnet*, and the condition of the iron in that state, with various other connected phenomena, are comprised under the name *electro-magnetism*.

If an electro-magnet, consisting of a small bar of iron round which a covered copper wire is spirally coiled, as shown in fig. 355, be freely suspended, so that the free ends of the spiral may dip into the mercury contained in the small wooden apparatus, figs. 351 *B* and 352 *A*, it will place itself with considerable energy in a direction from north to south, or more exactly from nearly north-north-west to south-south-east; the northern end will point somewhat to the west, the southern a little to the east. The ends of an electro-magnet, and generally of every piece of iron in the magnetic state, are called its *poles*; that end of a freely suspended electro-magnet which points towards north

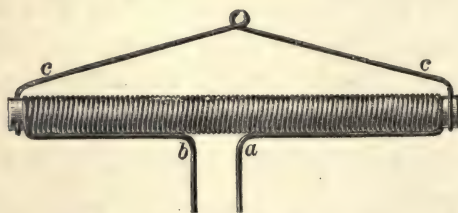


FIG. 355 (real size).

is the *north pole*, the end which points towards south the *south pole*.

If, while the electro-magnet is in its north-south position, the direction of the current in the spiral, and therefore also of the Ampèrian currents in the bar of

iron, be observed, it will be found that, as in the last experiment of the preceding article, the current ascends on the side of the coil turned towards the west, and descends on the east. If the observer stands south of



FIG. 356 (*Can. proj.*).

the spiral, and looks upon the south pole of the electro-magnet, the direction of the current is that of the arrow in fig. 356 A; if he stands north of the spiral, and looks at the north pole, the direction is that at B; and finally, when seen from the side, the currents in a magnetic body flow in the direction of the arrows in C, where *n* and *s* indicate the north pole and the south pole respectively.

We may then establish the following rule:—*The south pole of a magnet is that end at which the direction of the Ampèrian currents is the same as that of the motion of the hands of a watch.*

In the preceding figure and in some that follow, the currents are represented as traversing only the outside of the electro-magnet. This is strictly correct only as far as the current in the spiral is concerned; but in a magnetic piece of iron we have an infinite number of small currents each flowing round an individual mole-

culé. A more correct representation of this state is that in fig. 357 *A*, which at the same time exhibits the effect of the current flowing through one of the coils of the spiral (represented by the outer black arrow) in causing the Ampèrian currents (represented by the small white arrows) to flow all in the same direction and parallel to itself. If we carefully inspect the direction of the currents, first in the central molecule, and then in each of the molecules adjoining it, we

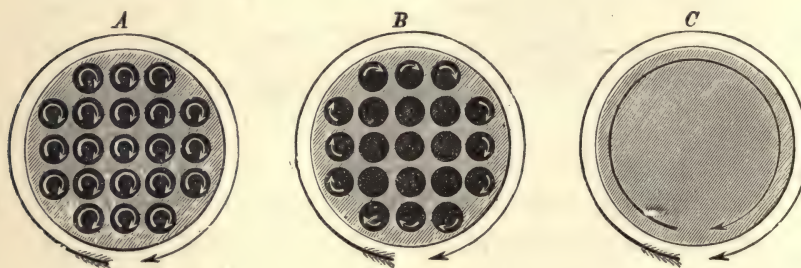


FIG. 357.

shall see at once that everywhere the adjacent parts of the current in two adjoining molecules flow in opposite directions. For example, on the right side of the central molecule the current descends, while on the left side of the adjoining molecule *on the right* it ascends; in the upper portion of the central molecule the current flows from left to right, in the lower portion of the adjoining molecule *above it*, it flows from right to left, and so on; in every two adjoining portions of two molecules the currents oppose one another, and consequently cannot exercise any external action. This is not the case with the surface; there the outer portion of each molecular current is no longer in close vicinity to another opposite current, and its action is therefore

not neutralised. The ultimate external action may therefore be represented as at B in fig. 357, or, since all these small active portions of these currents are at infinitely small distances from each other, as at C , which represents them as a single current. The active current is therefore also in the succeeding figures legitimately represented as a single one which traverses the outside of a magnet.

When the current is transmitted through two electromagnets, one of which is suspended and can freely move, while the other is held in the hand, powerful attraction or repulsion takes place when one pole of the latter is brought near to either pole of the suspended magnet. If the direction of the current in both magnets be observed, and their poles be determined in accordance with the above rule, it will be found that the north pole of one magnet attracts the south pole of the other magnet, but that north pole repels north pole, and south pole repels south pole. *Poles of the same name repel, and poles of contrary name attract one another.*

These phenomena are an immediate consequence of the previous laws. In fig. 358 A let two electromagnets be represented by a and b , and the direction of the current by the arrows. These directions are the same in both magnets, hence attraction takes place, and applying the above rule which determines the name of the pole from the direction of the current, s_1 and s_2 are seen to be south poles, n_1 and n_2 north poles, and the two ends turned towards each other, that is, the south pole s_1 and the north pole n_2 , attract each other. When a and b are in the position B of fig. 358, the current in one flows in an opposite direction to that

in the other; in b the current is seen by an observer at n_2 to flow contrary to the direction of the hands of a watch, hence n_2 is a north pole and s_2 a south pole, and the two like poles, s_1 and s_2 , repel each other.

When the two electro-magnets are not both in the

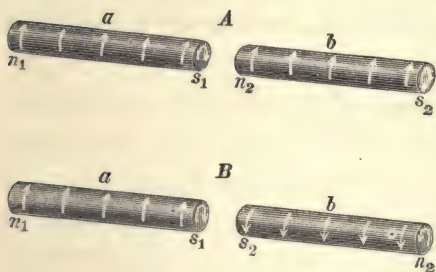


FIG. 358 (*an. proj.*).

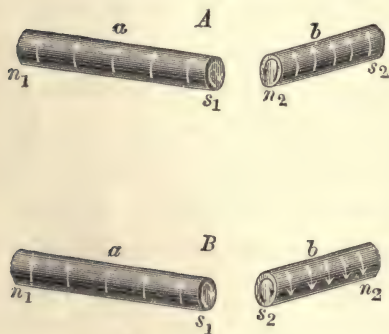


FIG. 359 (*an. proj.*).

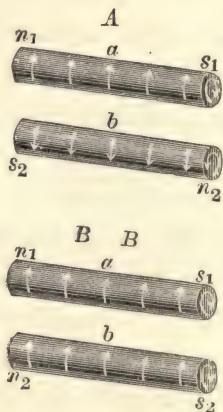


FIG. 360 (*an. proj.*).

same line, as in the case just considered, but are inclined to each other at any angle, or are placed side by side, it is no longer possible that the whole of the currents of both magnets can be in the same or opposite directions. In these cases the mutual behaviour of the two magnets depends on the direction of those portions of the currents in each magnet which are in close vicinity to each other, because the action of currents

on each other diminishes as the distance between them increases, and the mutual action of those currents which are near to each other will therefore have a preponderance over that of currents more remote from one another.

In fig. 359 *A* and *B*, the north poles of the two electro-magnets *a* and *b* are again denoted by n_1, n_2 , and the south poles by s_1, s_2 , and the magnets are supposed to be placed at right angles to each other. The two portions which in this position are nearest to each other are two edges, viz., the right edge at one end of *a*, and the left edge of one end of *b*, and the current in either magnet flows along these edges in a downward direction, hence attraction takes place between the contrary poles s_1 and n_2 ; attraction takes place, for the same reason, between n_1 and s_2 , but it is insensible in consequence of the distance between these two poles. In the position *B* the currents in the nearest edges flow in a contrary direction, hence there is repulsion between s_1 and s_2 .

Finally, if the electro-magnets are placed side by side or one above the other, as in fig. 360, and contrary poles are on the same side, as at *A*, the currents flow in the same direction in those portions of the two magnets nearest to each other, that is, in the lower side of *a*, or the upper side of *b*; mutual attraction is the consequence. But if, as at *B*, like poles are on the same side, then the nearest portions of the current in either magnet are opposed; hence the magnets repel each other.

For the contrivance fig. 353 a piece of glass tubing, 8 or 9^{cm} long and 5^{cm} wide, and some insulated copper wire, 0^{mm}·6 thick without

the covering, are required. The end of the tube where the spiral is to commence should be heated until a little sealing-wax melts upon it, and the coiling of the wire should be begun before the wax cools, so that the first turns can be pressed into the sealing-wax, and may thus be secured. After that the turns are wound on very closely and uniformly, until a little more than half the tube is covered; about forty-five or fifty turns will be requisite for the first layer. A stick of sealing-wax is then held in the flame, and the last turns are just touched lightly with the soft wax to cement them together. When the wax is cold the wire is wound round the tube in the same direction, but the coil is now made upon the top of the other, and placing again each turn close to the preceding one, the last turn will be on the top of the first, and must be secured either with a little sealing-wax or fastened with thread, taking in either case care that the wire cannot unwind itself. At the beginning and end of the coil a free end, 10^{cm} in length, must be left.

The end at the uncovered side of the tube is closed by a small cork of suitable size. The small bar is a piece of iron wire, 4 or 4^{cm}·5 long and 1^{mm}·5 thick. To attract this bar vertically upwards, the tube being held in a vertical position, it is sufficient to employ the current of two strong cells.

When the tube is held horizontal, and the current is interrupted at the moment when the bar moves with greatest velocity, in consequence of the attraction exerted upon it, the bar may be made to shoot out of the tube altogether. The bar is drawn inside the coil by the current, and if the current suddenly stops while the bar is moving rapidly onwards, the motion is continued solely in consequence of the inertia of the bar; but if the current is constant the attraction overcomes the inertia, and the bar is soon brought to rest within the coil. For this experiment one end of the spiral is clamped permanently to one of the terminals of the battery, while the other terminal is drawn by the hand along the second end of the spiral, so that the circuit is only closed for a short time.

For the experiment on the mutual attraction of several pieces of iron it is best to take thicker iron wire than for the first experiment; it should be almost as thick as the bore of the tube is wide, so as just to go in. The pieces to be attracted are of the same thickness, but only 15 or 20^{mm} long.

In experiments in which it is not intended to show the attraction between the spiral and the bar of iron, but when iron is simply to be made magnetic, as in the movable electro-magnet, fig. 355, the insulated copper wire may be coiled round the bar itself. For this

electro-magnet an iron wire is used, 6^{cm} long and 4^{mm} thick. A piece of paper is first smoothly fixed round it with paste, leaving only the ends free; the paper protects the covering of the copper wire against contact with iron rust, which is gradually formed on the bar, and which would destroy the covering. For the electro-magnet only one spiral is required; the last turns at each end are tied with thread, and bent into the shape shown in fig. 355, leaving one end to stand out just from the middle of the electro-magnet and the other 6^{mm} from it. At *a* and *b* the ends are secured with thread. A frame, *cc*, made of wire, serves for suspending the electro-magnet; it has a ring in the middle, and at the ends suitable hooks, into which the bar is placed.

The second electro-magnet required is made of the same size, but the free ends of the spiral are left a little longer, and they need not be bent towards the middle.

The action of a magnetic piece of iron to produce parallelism of the Ampèrian currents in another piece of iron, and to effect the magnetisation of the latter, is termed *magnetic induction*. In fig. 358 *A*, *a* may represent an electro-magnet with its currents, and *b* an ordinary bar of iron; the end *n*₂ of the latter, which is directed towards the south pole *s*₁ of the electro-magnet, must evidently become a north pole if the magnetic bar *a* causes parallelism of the currents in *b*, or generally, *that end of a bar of iron which is nearest to one of the poles of a magnet becomes by magnetic induction a pole of contrary name*.

An electro-magnet which is U-shaped, or is angular (\sqcap), a so-called horse-shoe magnet, is capable of supporting a piece of soft iron which connects its poles with considerable force. A piece of iron of this kind is called a *keeper* or 'armature.' Such a keeper becomes magnetised under the influence of both poles. Thus if the pole of the electro-magnet, fig. 361 *A*, which is on the left side, is a south pole, the adjoining end of

the keeper becomes a north pole ; the other end therefore a south pole. This other end again becomes also a south pole by the inductive action of the adjoining pole of the electro-magnet, which is a north pole. Thus either pole produces not only the effect which is due to its individual influence, but it also adds to the action of the other, and the total attraction exerted by both poles together is consequently more than double that which

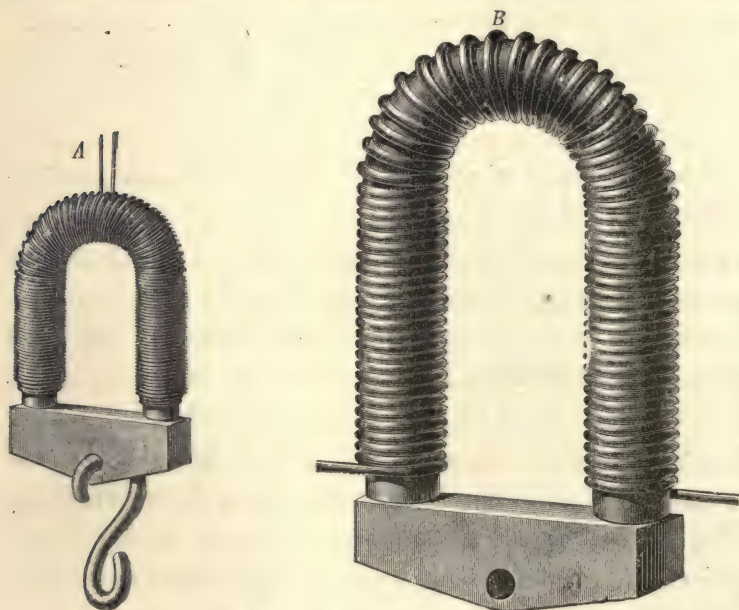


FIG. 361 (*an proj. ; real size*).

would be exerted if each pole were to act alone. Thus the small electro-magnet represented in fig. 361 *A* will support, by means of a keeper, a weight of several hundred grammes ; the larger electro-magnet, fig. 361 *B*, will support a considerable number of kilogrammes, the current of a single Grove's or Bunsen's cell being used in either case. With very large electro-magnets,

consisting of horse-shoes of considerable size, round which a vast quantity of stout copper wire is coiled, weights of several thousand kilogrammes may be supported.

The attraction of electro-magnets has been variously applied for the construction of electro-magnetic engines for the production of continued motion. On a small scale the current will often render great service as a source of motion, as, for example, for producing rotatory motion in a siren, stirring a liquid by means of a paddle wheel in a small vessel, or for similar purposes. But for performing a large amount of work electric engines have not proved themselves equal to steam engines, because their effect does not increase in proportion to their dimensions, and also because the maintenance of batteries capable of producing sufficiently strong currents is much more expensive than the fuel required for heating the water in a steam-boiler.

A very simple contrivance for producing continuous motion by electro-magnetism is represented in fig. 362 *A*, in which *ab* represents a horse-shoe electro-magnet with its poles turned downwards and fixed to a small wooden board. Another electro-magnet, *cd*, which is straight, can turn within the legs of the horse-shoe about a vertical spindle with conical pointed ends, of which the upper one fits into a small cavity in the screw *f*, which passes through the horse-shoe, while the lower rests in a similar cavity of the metal piece *e*. When *cd* turns, the ends of the spiral coiled round it glide along the metal pieces *g* and *h*, each of which is nearly a semicircle. The terminals of the battery are connected with the apparatus at *i* and *k* by binding

screws. The positive pole being connected with *i*, the current enters the spiral of the horse-shoe at *a*, and from the direction which it has there it follows that *a*

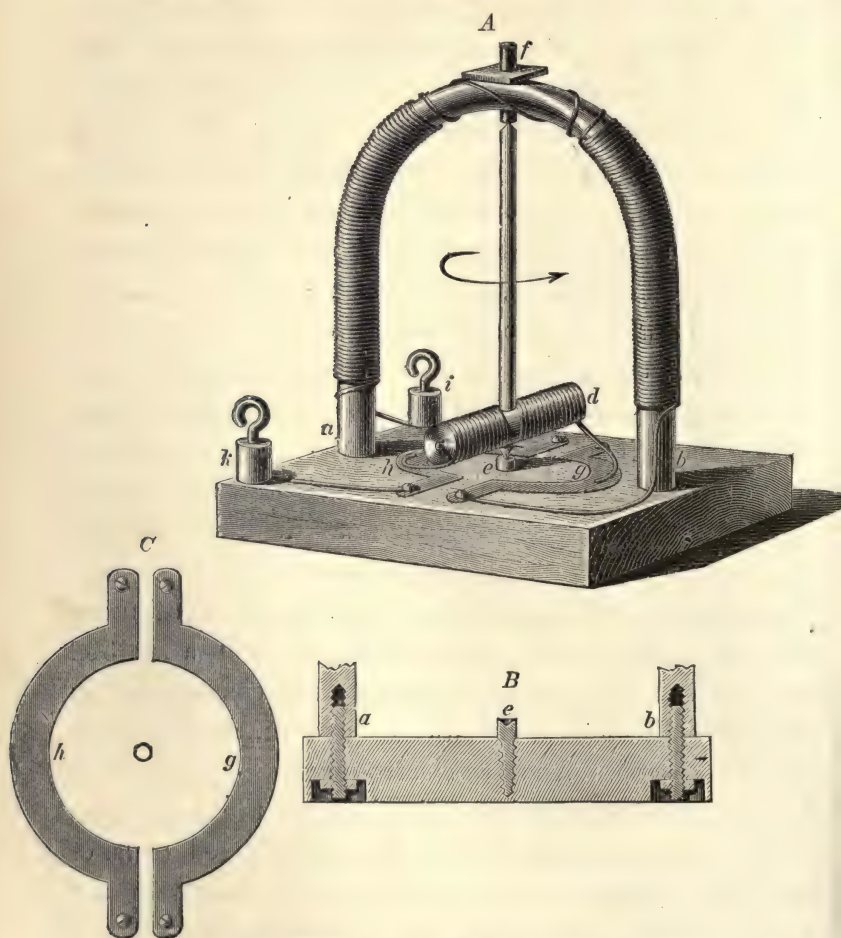


FIG. 362 (*A an. proj.*; *A, B, C, ½ real size*).

is a south pole, while *b* becomes a north pole. From *b* the current passes to the semicircular piece *g*, and enters the spiral of the straight electro-magnet at *d*, making *d* a north pole and *e* a south pole. Finally the current

passes out through the piece *h* to *k*. At starting, *a* and *c* are thus south poles, and *b* and *d* north poles; repulsion therefore takes place between *a* and *c* and between *b* and *d*, that is, the straight magnet will begin to rotate in the direction of the arrow; *c* approaches *b*, and *d* approaches *a*. This motion would cease as soon as *c* is close and opposite to *b*, and *d* to *a*, for contrary poles are then in juxtaposition, and the attraction is greatest; but at the moment when the movable magnet is thus in a straight line between the two legs of the horse-shoe, the free ends of the spiral around it reach the intervening space between the metal pieces *h* and *g*, and are no longer in contact with a metallic conductor; hence the current is interrupted, and the attraction between *c* and *b* on one side, and *d* and *a* on the other, ceases instantaneously. The consequence of this is that *c* does not really stop when opposite to *b*, but by its inertia moves a little beyond *b*, while in the same way *d* does not stop opposite to *a*, but continues its motion until it is a little in front of *a*. In this position, however, the free ends of the spiral are again brought in contact with the pieces *h* and *g*, but now the free end which proceeds from *d* is in contact with *h*, the free end from *c* touches *g*; the current is again closed, but it traverses the spiral of the movable magnet in a direction exactly opposite to that which it had at first; it enters at the end *c*, making *c* a north pole, and leaves the spiral at *d*, making *d* a south pole. Since *b* remains a north pole, and *c*, which is a little behind it, has now also become a north pole, *c* is repelled farther away from *b*, that is, the motion is continued in the direction of the arrow. Repulsion with similar effect

takes place between *a* and *d*, *d* also being urged in the direction in which it began to move ; and then, after a complete revolution has been accomplished, the poles are again reversed, and the motion is continued.

The electro-magnet, fig. 361 *A*, is prepared of iron wire, 5^{mm} thick, which is made red hot and hammered into shape with the mallet, the hot wire being placed upon a small round piece of iron which is clamped in the vice (fig. 48, page 57), or one of the beaks of the parallel vice (fig. 49) may be used for the purpose. First the poles are filed flat, paper is pasted round the horse-shoe as far as the coil will touch the iron, and then the wire (0^{mm}·6 thick) is wound on, beginning at the middle of the bent portion. From the middle the wire is wound round until one pole is reached, then a second coil is wound round on the top of that portion, going back to the middle and proceeding to the other pole, where again the wire is taken back to the middle. The free end of the wire left at starting is held fast by the superposed coil, but the second end should be tied with thread if it appears loose; it frequently becomes squeezed between the adjoining turns, and remains firm without further fastening. The keeper is filed into the shape shown in the figure out of a small piece of bar iron; a hole is drilled through it and provided with a wire hook for suspending weights.

The thin wire of this small electro-magnet is sensibly heated by the current of a strong cell; by that of two cells the heating effect is generally so great that it is impossible to hold the magnet in the hand. With one Meidinger element it will have a 'lifting power' of about fifty grammes. If four coils are wound round it instead of two it could support nearly 200 grammes.

The horse-shoe required for the larger electro-magnet, fig. 361 *B*, and *a b* in fig. 362, will have to be forged out of round bar iron by a blacksmith; the keeper for the electro-magnet, fig. 361 *B*, should also be hammered into shape on a smith's anvil, so as to diminish the work of filing as much as possible. The wire for the spiral should be 1^{mm} thick (without covering) or a little more; one coil is sufficient for obtaining a considerable lifting power when two strong cells are used. A Meidinger cell is too weak in this case, as its effect upon a large piece of iron with so few turns in the coil is scarcely perceptible. So thick a wire needs no special fastening; if the turns are close together, and each of them is drawn as tight as possible in winding on the wire, it will not unwind itself afterwards.

Three holes are drilled in the horse-shoe for the apparatus fig. 362, and in each of them a hollow screw is tapped; one, in the middle of the bend of the horse-shoe, receives the screw *f*; the two others are cut into the ends of the legs. Into these, two brass screws are fitted, which serve for attaching the horse-shoe to a wooden support; as shown in fig. 362 *B*, the screws pass through holes in the wood and are tightened by nuts. The small piece of metal *e* must be fixed exactly in the middle between *a* and *b*. It is best to use for it a short thick wood-screw, from which the head is removed with the metal saw. The top is then filed smooth, and a small depression made in the middle with the centre-punch, which is afterwards drilled a little deeper. The piece is screwed into the wood with the hand-vice before the electro-magnet *a b* is fixed.

The screw *f* is made of cast steel; in the lower end of it a cavity is made like that in *e*, and in the upper end a notch for the screw-driver is made with the narrow cutting edge of the flat file. To prevent the vibration of the screw *f* during the rotation of the spindle it is clamped by a square nut, a so-called 'jam-nut,' which is firmly screwed against the bend of the horse-shoe after *f* has been adjusted in its proper position.

The iron core for the straight electro-magnet *cd* must be 2mm shorter than the distance between the legs *a* and *b*. A straight hole is drilled accurately through the middle of it, and the hole is widened with a broach until the piece of cast steel which is to serve as spindle passes rather tightly through it. The ends of the spindle are made conical and pointed with the file; the points especially must be filed very smooth, so that they may move in the cavities of *e* and *f* with as little friction as possible. To render the motion still more smooth a small drop of oil is poured into each cavity. The spindle is fixed to the core by a bit of soft solder.

The metal pieces *g* and *h* are first roughly cut with the chisel out of a sheet of brass, 1mm thick, and shaped by the file into the form shown at *C* in fig. 362. The projecting parts at each end of the arcs serve for fastening the pieces to the wooden support by means of wood-screws with round heads. At the end of the spiral wire which connects *b* with the piece *g*, and also at the end of the terminal which leads from the screw *k* to the piece *h*, small loops are made which are placed round two of the wood-screws; when these are turned they fix the pieces *g* and *h* on one side, and serve at the same time, as shown in the figure, for clamping the ends of the wires which connect the semicircular pieces with the electro-magnet and the binding screw *k*.

In order to make the ends of the spiral which glide along the sur-

face of g and h move smoothly, the gap between g and h on each side must be filled up by a small piece of wood, which is cut of the exact width of the gap and pushed into it; after it is firmly fixed, as much is taken off from its thickness as will make its upper surface exactly flush with that of g and h . After the apparatus has been used several times, a conducting layer of metallic dust is generally rubbed off and deposited in the path of the wires; this would obviously render the apparatus useless, and the pieces of wood must therefore be replaced by others as soon as such a deposition of metal is perceived. To secure the wooden pieces better it is advisable to file the edges of the metallic projections somewhat slanting, so as to make the space between them wider below, where they are in contact with the wooden support, than above.

The ends carried downwards from the spiral round cd must just touch the wood between the projections when cd is in a line with ab , and in every other position they must be in proper contact with the surface of g and h respectively, but not press upon the metal, for such a pressure would considerably increase the friction, and the motion of the apparatus would thus be rendered quite impossible; on the other hand, if their contact with the metallic surface is anywhere imperfect no current can flow through the apparatus, and therefore no motion can be produced.

The strength of the current required for producing motion depends entirely on the nicety with which the apparatus is constructed. For an apparatus which is very carefully and neatly made a single Grove or Bunsen cell is sufficient; two cells will give motion to an apparatus which has been less carefully constructed.

The most important application of electro-magnetism is *electric telegraphy*, that is, the transmission of signals to considerable distances. The application rests on the great velocity with which a galvanic current is propagated in a conducting wire, and on the fact that the attraction of an electro-magnet takes place at the instant of closing the circuit, and ceases again when the current is interrupted.

The velocity of the galvanic current in a telegraph cable is considerably less than that given above for the discharge of a Leyden jar; nevertheless, currents trans-

mitted through telegraph wires have traversed distances at the rate of over twenty-seven millions of metres, or a little more than 17,000 English miles, in one second. The time required by the current to traverse a circuit many miles in length is therefore indefinitely small.

When a keeper has been attracted by an electro-magnet, and is in contact with its two poles, the attraction does not cease completely when the current is interrupted; when not too much weighted the keeper remains adhering to the poles until it is torn off. When contact is once broken in this manner by the application of force, the keeper will not again be attracted unless the current is transmitted anew through the spiral of the electro-magnet. In order to render the attractive force exerted by electro-magnets upon iron available for electric telegraphy, it is most important to prevent the effect of this residual attraction, and this is effected by interposing some substance between the bar to be attracted and the poles of the electro-magnet, which prevents direct contact between them. Thus if a thin sheet of paper be placed between the keeper and electro-magnet in fig. 361, the keeper, after being attracted while the current lasts, will immediately drop when the current is interrupted. The lifting power is of course diminished by the interposition of any substance between the electro-magnet and the iron bar; but this is of no consequence in the present application of electro-magnetism.

Let one of the poles of a battery be in metallic connection by means of a wire with one end of the spiral of an electro-magnet erected at a considerable distance from

the battery, and let the other end of the spiral be similarly connected by a conductor with the second pole of the battery, then the distant electro-magnet may be magnetised at will by closing the circuit, and again demagnetised at any instant by breaking it. If now a bar of iron be placed at a small distance from the poles of this electro-magnet, but pulled away from it by a spring of not too great strength, when the current passes through the spiral, the force of the spring is overcome by the attraction of the electro-magnet and the piece of iron approaches it; then by making or breaking contact the motion to and fro of the bar of iron may be controlled at will at any distance from it, and the mode of setting the bar in motion may be so varied as to constitute a preconcerted system of signals.

Many different arrangements of the electric telegraph have been devised, but the following description of a *Morse's Writing (or Printing) Telegraph*, in its most simple form, will give to the student a sufficient insight into the principles applied in such an apparatus, and into the general mode of its working.

The electro-magnet *ee*, fig. 363, consists of two small cylinders of iron, placed upon a common support of the same metal, which replaces the bend of a horse-shoe and forms the connection between both legs. The spiral wire is not wound upon the iron itself, but upon two small 'bobbins' of wood, into the hollow interior of which the iron cores fit exactly. Near to the poles of the electro-magnet is the keeper or 'armature' *a*, fixed at the end of a horizontal lever, *h*, movable about an axis, *c*, which turns in two holes made in the brass plates *pp*. At the other end of the lever there is a

screw of steel, *s*, with a blunt point, which serves as a pencil for writing the signals. The spring *f* pulls the right arm of the lever downwards, and by means of two screws, *b* and *d*, the amplitude of the oscillations of the lever is regulated; *b* prevents the left arm of the lever from descending so far that armature and poles are brought into direct contact when the current acts, and *d* prevents the right arm from descending too much by the action of the spring, and thus maintains the arma-

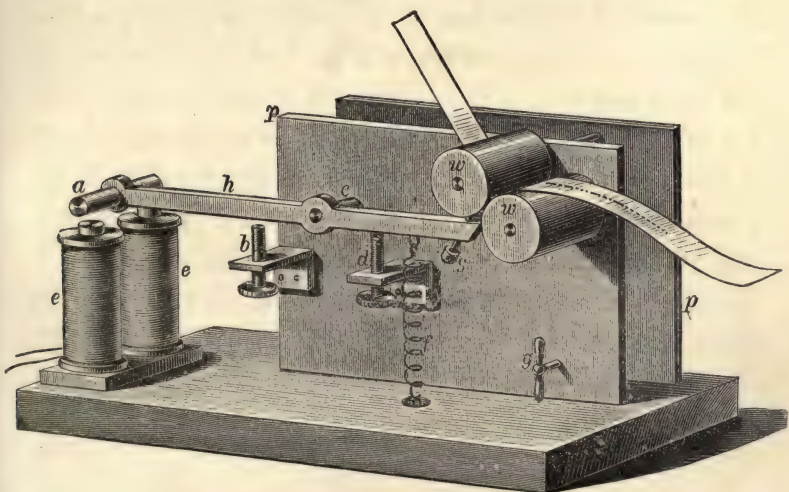


FIG. 363 (*an. proj.*; $\frac{1}{2}$ real size).

ture at a suitable distance for being attracted. Two small rollers, *ww*, are turned in contrary directions (the lower one in the direction of a watch hand) by means of clockwork placed between the plates *pp*, the motion of which is capable of being started or stopped at will by means of turning the handle *g* either to the left or to the right. When the clockwork is set in motion a band of paper passes onwards between the two rollers, a large quantity of the paper being rolled round

a drum not shown in the figure, from which it is rolled off as required.

The paper being set in motion, and the current transmitted through the electro-magnet, the armature *s* will be attracted, and the point of the screw *s* is pressed against the moving paper. The upper one of the two rollers has a small groove around it, and as the point presses the paper into this groove an indentation is produced, the length of which depends on the time during which the point is in contact with the paper. If the current is interrupted an instant after it was closed a *dot* (·) is produced, otherwise a *dash* (—). By varying the length of time during which the circuit is open or closed, dots or dashes, or any required combination of them may be produced at a distant station, and it is only necessary to give definite meanings to these combinations in order to be able to represent by them the letters of the alphabet. The telegraphic alphabet now universally used in connection with Morse's printing telegraph is the following:—

A — —	J — — — —	R — —
B — — —	K — — —	S — —
C — — — —	L — — —	T —
D — — —	M — — —	U — — —
E —	N — —	V — — — —
F — — — —	O — — — —	W — — — —
G — — — —	Ö — — — —	X — — — —
H — — — —	P — — — —	Y — — — —
I — —	Q — — — —	Z — — — —

The dots and dashes which together form the same letter are separated by small intervals, the letters by larger intervals, and the single words by still larger ones.

That part of a Morse's telegraph which has just been described is usually called the 'indicator.' For closing and breaking the circuit, the 'communicator,' or 'key,' shown in fig. 364, is used. It consists of a small wooden

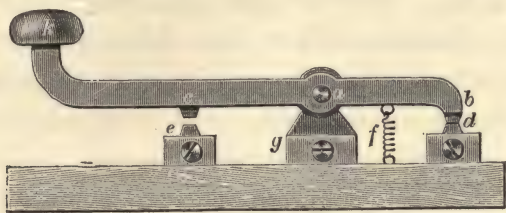


FIG. 364 ($\frac{1}{4}$ real size).

base, which acts as support for a metallic lever, movable on the axis *a*. The end *b* of the lever is ordinarily drawn downwards by the spring *f*, but by pressing the handle *k*, the other arm of the lever is lowered and *b* is raised. At *c* and *b* there are small studs of steel or platinum, attached to the lever, which may be made to strike upon similar studs *e* and *d*, and thus to produce 'contact,' either between *c* and *e* when the key is pressed down, or between *b* and *d* when the key is at rest. The metal pieces *d* and *e*, as well as the piece *g*, which supports the axis of the lever, are provided with binding screws for attaching the conducting wires; these are usually simple screws with broad flat heads, which clamp the wires placed beneath them.

For the telegraphic connection of two stations, I. and II. in fig. 365, there are required two batteries, two indicators, two communicators or keys, and a complete circuit formed by two conductors. One of these is formed by the 'line wire,' usually of iron, while the earth itself is used as the second conductor. For this purpose two large plates of copper, *e*₁ and *e*₂,

are sunk to some depth in the ground, and each of them is connected by a wire with one end of the line; the current then passes in one direction along the wire, and returns in the opposite direction through the earth. The earth is a worse conductor than the metals and even than common water; but a comparatively bad conductor which is very thick transmits a current more readily than a much better conductor which is very thin; for example, of two wires of equal thickness, one of copper and the other of iron, the copper wire conducts much better than the iron wire; but if the thick-

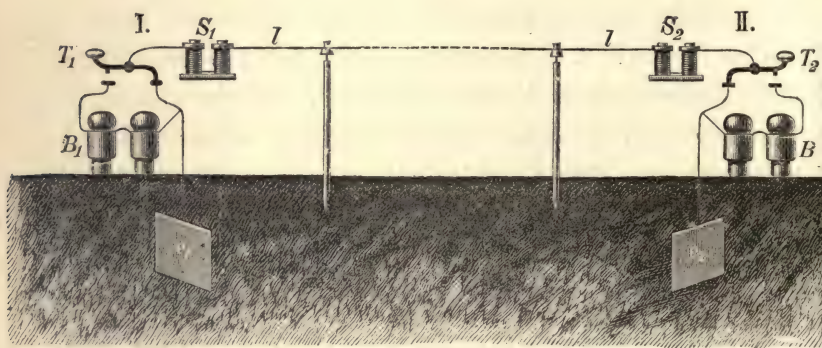


FIG. 365.

ness of the iron wire is many times as great as that of the copper wire, it conducts electricity much better than the copper wire. In the same way the earth, being of almost infinitely greater thickness than the metallic wire, is far superior to it as a conductor. B_1 and B_2 are the two batteries, T_1 and T_2 the two keys, S_1 and S_2 represent the electro-magnets of the indicators, the other parts of which are left out for the sake of simplicity. The electro-magnets of the two stations are connected by the line ll , which is suspended by insulat-

ing bell-shaped supports of porcelain or glass, fixed upon posts or against the sides of buildings. Each of the electro-magnets is in conducting communication with the axis on which the lever of the communicator or 'sending key' turns, and, in the ordinary position of the key, it is also in connection, through the contact studs at the farther end (b and d , fig. 364), with the earth and with one pole of the battery, while the second pole of the battery is connected by a wire with the stud, with which the key makes contact when pressed down. This is the state of matters shown in fig. 365, and in this state, when the keys at both stations are *up*, no current is transmitted, because only one pole of each battery is connected with the circuit. Now let the key at station I. be pressed *down*. The pole previously free is now connected by means of the front contact studs with the lever of the key; accordingly the current passes along the lever to the axis, thence through the spiral of the electro-magnet at station I., along ll to station II. and the electro-magnet there, through the key at station II. to the plate e_2 and then through the earth, and so back to the other pole of the battery. A corresponding effect is produced if T_1 remains at rest while T_2 is pressed down at station II. In general, whenever one of the two keys is pressed down, a complete circuit is established, the armatures of both electro-magnets are attracted, and the signals despatched at one station are simultaneously formed on the moving paper at both stations. To save paper, however, the clockwork is only set going at the *receiving* station, not at that from which the message is being sent. The attention of the clerk at the receiving station S_2 is

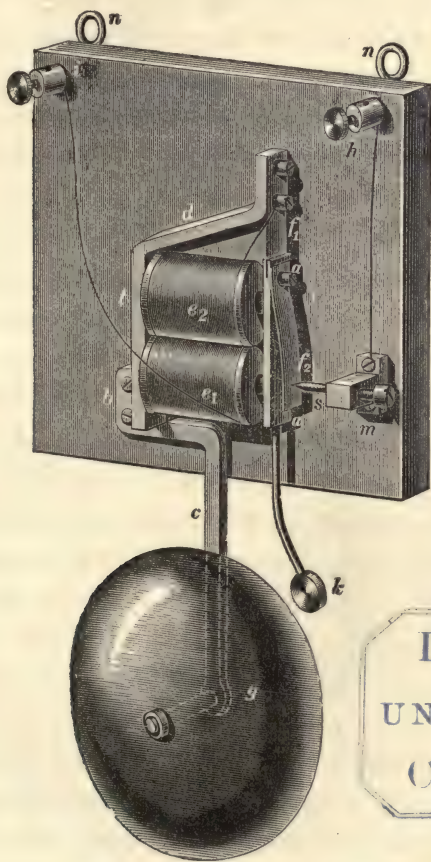
called before sending the message by pressing down the key at S_1 several times in rapid succession, whereby a clicking of the armature is produced at S_2 ; the clerk thereupon turns the catch g , fig. 363, sets the clockwork in motion, sends back a clicking or other signal to S_1 that he is ready, and the printing begins. Several additional pieces of apparatus are required in the actual working of the telegraph, which, however, cannot be considered here.

A useful application of electro-magnetism often used is the electric bell in hotels, manufactories, etc.

The electro-magnet $e_1 e_2$ in fig. 366 consists of two bobbins of copper wire with small cores of bar iron fixed by screws or solder to an iron bar t . The bar t , which replaces the bend of a horse-shoe magnet, has three projections, b , c , and d . The first, b , serves for attaching t to the small wooden board which supports the whole contrivance; c carries the bell; and to d a flat metallic spring, f_1 , is fixed. The spring f_1 carries the armature $a a$, to the end of which the hammer k is fixed, which strikes the bell. To the back of the armature another flat spring, f_2 , is attached, which presses gently against the pointed end of the brass screw s . The nut m of this screw is connected by a wire with the binding screw h , and one of the ends of the spiral of the electro-magnet is similarly connected with the binding screw i ; h and i serve for connecting the apparatus with the terminals of the battery. The second end of the spiral is clamped by a screw-head to the flat spring f_1 . The whole is usually suspended to the wall by rings, $n n$, and protected against dust or damage by a small wooden box (left out in the figure), with two apertures,

which allow the handle of the hammer and the bar which carries the bell to pass through.

When h and i are connected with the terminals of a battery a complete circuit is established. The current,



LIBRARY
UNIVERSITY
CALIFORNIA

FIG. 366 (*an. proj.*; $\frac{1}{2}$ real size).

supposing i to be connected with the positive pole, passes from i round the bobbins e_1 and e_2 , from e_2 to f_1 , through the armature a to f_2 , and thence through s and m to h ; if h be connected with the positive pole the

current of course traverses this circuit in an opposite direction. The effect of the passage of the current through the spiral is to cause the armature to be attracted, and when this happens the hammer k strikes the bell; but at that instant contact ceases between the spring f_2 and the extremity of the screw s , the current is therefore interrupted, and as there is no attraction now between the bobbins and the armature, the bar a is brought back by the spring to its original position, and contact is again made with s . As soon as the circuit is completed again, the same action is repeated, and in this way the keeper is kept in a state of rapid oscillation, and the hammer k keeps on constantly striking the bell.

If h and i were permanently connected with the battery the bell would ring constantly. A *key* or *push-button* is therefore inserted in

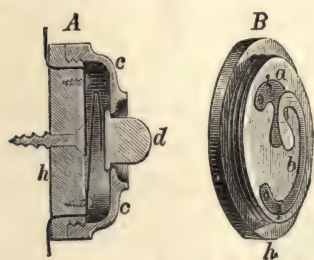


FIG. 367 (*B. an. proj.*; *A and B*
 $\frac{1}{2}$ real size).

some part of the circuit which allows of conveniently closing the circuit only when required. Fig. 367 *A* shows a section of such a key, while *B* represents the internal arrangement. A disc of wood, h , is fixed to a

plug in the wall by a screw which passes through the disc. Two pieces of sheet brass are screwed to the disc; one of them, a , lies flat with its whole surface in contact with the wood; the other piece b , forms a spring, and is screwed to the wood and in contact with it at one end, while the remainder stands a little off from the wood. The edge of the disc has a screw cut into it, so that a cover, cc , may be screwed upon it; the cover

has an aperture in the middle, through which a button, *d*, usually of porcelain, passes. The button is pressed underneath by the spring *b*, but is kept from being forced out by a small ledge around it, which is pressed by the spring against the cover. When the button is pressed down, the spring *b* comes in contact with the metal piece *a*, and the circuit is completed, because *a* and *b* are respectively connected with the wires leading to the poles of the battery, the ends of these wires being clamped by the heads of the screws which serve for fastening *a* and *b* to the wooden disc. The key is of course fixed at the place from which it is desired to ring the bell; the battery may be erected near the bell if convenient, or near the key, or anywhere between them. One of the binding screws of the bell is connected with one pole of the battery, the other binding screw with one of the metal strips of the key, and the second metal strip of the key is connected with the other pole of the battery. The bell then rings and will continue to ring as long as the button is kept pressed down.

Meidinger's elements are the best for electric bells, as they need only be renewed about once a year. One cell will give a sufficiently strong current for a single bell, if the circuit is not too long. Copper wire should always be used for the connections; iron wire soon becomes rusty, and then breaks very easily unless it is very thick; but in that case it is inconveniently stiff and is not easily bent so as to fit the angles of walls, etc. Copper is also by far the better conductor. Copper wire covered with cotton thread of various colours, so as to suit the colour of the wall along which the wire is fixed, is often sold for electric bells, but is not to be recommended; the insulation of the covering is soon rendered imperfect by the wearing away of portions of the thread, in consequence of which the moisture of damp walls finds its way between the wire and the covering. Common uncovered copper bell wire, 1^{mm} thick, answers

quite well, provided that the wires are nowhere placed too near one another. The walls along which the wires run are by no means perfect non-conductors; a small part of the current will therefore pass through the wall from one wire to another near it. The effect of this is insensible if the wires are 5 or 6^{cm} from each other, but if they are nearer to one another the action of the current might be seriously disturbed. The wires are generally attached by means of small tacks or wire hooks; they are driven into the plaster of the brickwork, and the wire is wound round them. It is, however, better to fix with pegs small pieces of wood, 10 or 20^{mm} thick and 2 or 4^{cm} wide, at distances of a few metres along the wall, and then to stretch the wire by small screws which are fastened into the pieces of wood, so that the wall is nowhere touched by the wire.

For offices in large buildings, manufactories, etc., the arrangement of the wires is often rather complicated, and in that case several wires are placed side by side, mostly between the wall and the skirting board which runs along the flooring. Whenever wires are to be placed so near each other they must have an insulating covering. Nevertheless, it is usually found that after a time the covering becomes faulty, that the moisture which enters is decomposed by the current passing from one wire to the other through the fault, and that consequently verdigris is deposited and the wire gradually destroyed. The connecting wires should always be visible and easy of access, so that any faulty place may be at once discovered and the fault remedied.

Where the wires have to pass through the brickwork of walls, it can scarcely be done otherwise than by placing them close together within the opening of the wall. Wires covered with gutta percha, wax, asphaltum, or india-rubber are used in such cases, and the wires placed side by side in a glass tube, which is as long as the opening; the tube prevents contact between the wires and the brickwork, and protects them against moisture. The covered pieces of wire which project from the tube are soldered to the ends of the uncovered wire, which forms the continuation of the circuit. Similarly in all cases where wires have to be joined, this should be done by soldering.

In fig. 368 various arrangements for the circuit between battery, key, and bell are represented. *A* is the most simple, such as described previously; *t* is the key, *b* the battery, and *k* the bell. In *B* there are three keys, *t*₁, *t*₂, *t*₃, placed at various points of the circuit, as, for example, in three different rooms, from each of which the bell *k* may be rung. Where wires have to cross each other

without touching, as in *B*, and also in *C* and *D*, the lines representing the circuit are for a short distance replaced by dots.

In *C* there are two keys in one room, t_1 and t_2 . If t_1 is pressed k_1 rings in one room, and if t_2 is pressed k_2 rings in another room.

D shows an arrangement by means of which one bell may be rung in answer to another, a key and a bell being erected in each of the two rooms between which such a communication is to be established, the key t_1 rings k_2 , and t_2 rings the bell k_1 .

With a little attention the student will easily trace the path of the current in each of the preceding cases.

The crossing of wires without contact is easily accomplished, either by nailing a small flat piece of wood over one wire and leading the second wire over the wood, or by covering each wire at the crossing with a short piece of india-rubber tubing, and tying both wires together at the intersection if there is any risk of a displacement of the tubing.

An electric alarum like that in fig. 369 the student may easily construct for himself. The electro-magnet is a horse-shoe of iron wire, 5 or 6^{mm} thick, which is covered with four or six layers of covered copper wire, 0^{mm}.6 thick. It is fastened to a wooden board by means of a long screw, *h*, which passes through a small flat piece



FIG. 368.

of wood, l , 3 or 4^{mm} in thickness. The magnet is first placed in the proper position, and by tightening the screw it is permanently clamped. The keeper is cut from a piece of bar iron, and adjusted

to the proper dimensions with the file. Into one end of it a small hole is drilled lengthways, and at the other end a cut is made, also lengthways, with the metal saw; two holes are also drilled through the end where the cut is, and are both of them slightly countersunk at both sides. For the sake of clearness in fig. 369 the keeper is drawn in section, and the remaining parts in outline. For the hammer a piece of brass wire, 6mm thick and 12mm long, is cut, and a hole is drilled through it at the middle of its length. Into this hole one end of a piece of brass wire, 2mm thick, is soldered;

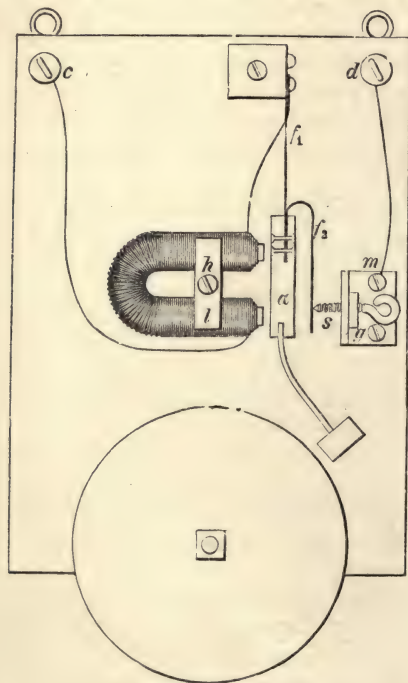


FIG. 369 ($\frac{1}{2}$ real size).

the other end of it is fastened with solder into the hole at one end of the keeper. Two strips of thin sheet brass are cut, each 6mm wide, made elastic by hammering, and provided with the necessary holes for fastening them. They are put both together into the slit at the end of the keeper, and secured by two brass rivets. A piece of brass wire, which is just thick enough to pass tightly through the two holes in the keeper, is heated in the flame, and two pieces are cut off it, long enough to project on each side about 0mm.5 when pushed into the holes. They are passed through the holes

of the keeper and brass springs, and then hammered flat into the enlarged entrance of the holes; the ends are then filed flush with the sides of the keeper. When the strips are thus secured, one of them (f_2) is bent in the shape shown in the figure, and the other is fastened by two short round-headed screws to a small square block of wood, which is screwed to the board by a long wood-screw. The hole in the little block through which this screw passes must be made somewhat wider than required, so that the block can be turned into the proper position before the screw is tightened. Beneath the head of one of the two small screws which fix the spring f_1 one end of the wire forming the coil of the electro-magnet is fastened, the covering being of course previously removed from the end of the wire which is to be clamped. The other end of the spiral is clamped to the binding screw c , which also serves for connecting the contrivance with one of the terminals of the battery. The other binding screw, d , is connected by a wire with a piece of brass m , 3^{mm} thick, which is bent at right angles, and has a hole for the screw s . A small jam-nut is screwed upon s , which serves for tightening it as soon as it is adjusted to the proper position. For the bell, either one of a large alarum clock should be used, or one of the small shallow steel bells (called 'gongs'), easily obtainable at the ironmonger's. To fix the bell a piece of brass wire, 3^{mm} thick, has a screw cut upon it from one end to the other, and two small nuts are prepared for it. The end of the wire is screwed into the wooden support; one of the nuts is then worked down the screw to the proper height, upon this nut the bell is placed, and finally secured by the second nut. The distance of the bell from the board should be such that the hammer strikes about the edge of the bell.

In setting the whole up the bell is fixed first. The keeper, with the springs and hammer, is then screwed to the little block. The block itself is now adjusted until the distance between bell and hammer is 2 or 3^{mm}, and fixed in that position by tightening the long screw which fastens it to the support. Next the electro-magnet is placed upon the support, and fixed in such a position that the keeper may be very near to its poles, but not quite in contact with them, when the hammer is made to touch the bell. Finally the end of the screw s must be brought not only in contact with the spring f_2 , but so as to *press* gently against it. This adjustment must be made by trial, c and d being connected temporarily with the poles of a cell.

The spring f_2 , which should be somewhat less strong than f_1 , is required for producing vigorous oscillations of the keeper and conse-

quently of the hammer. If the end of the screw s were in direct contact with the keeper, f_2 being altogether removed, the current would be always interrupted at the very instant when the keeper, in consequence of the attraction of the electro-magnet, has moved through the smallest possible distance; the keeper would then go back again immediately, because the current has ceased. It would again make contact, and again be attracted through quite an insensible distance, and so on; in other words, the 'amplitude' of the oscillations of the keeper would be so small that there would only be a buzzing sound, caused by the vibrations of the keeper and the attached pieces of metal. But since the end of the screw s presses gently against the spring f_2 , the tension of the spring is only gradually relaxed when the keeper is drawn towards the electro-magnet; the consequence is that the contact between f_2 and s , and hence the duration of the current, is maintained for some little time, and that when the contact really ceases the keeper has already moved through a sensible space and acquired an appreciable velocity. The amplitude of the oscillations of keeper and hammer is thus rendered sufficiently great for the hammer to strike against the bell; when the current stops, the keeper with its appendages is forced back into the former position by the tension of the spring f_1 , the end of s presses once more against f_2 , the circuit is again complete, the effect is repeated, and the ringing is continued.

Fig. 370 shows a key of easy construction. Two strips of sheet brass, one of them (in the figure the one on the right) made elastic by hammering and slightly bent, are screwed to a small board



FIG. 370 (*an. proj.*; $\frac{1}{2}$ real size).

by means of two wood-screws. The ends of the connecting wires are bent into loops, and these are clamped beneath the heads of the two outer screws. By pressing the bent strip down, contact is established with the straight one, and the circuit is closed; on releasing the strip the circuit is again opened, and the bell stops ringing.

A key of this kind may frequently with advantage be interposed in the circuit in many experiments on galvanic electricity and electro-magnetism; as, for example, in those on the heating effect of the current, and in using the various kinds of apparatus represented in figs. 343 to 345, 351 to 354, 361 and 362. It is best in

these cases to replace the two outer screws in fig. 370 by binding screws, which admit of more readily establishing connection with any other apparatus.

The small sparks produced whenever contact is broken cause the metal to become gradually oxydised at the parts which touch each other, unless they are made of some metal which does not become oxydised when heated in air. Such a metal is platinum, and if possible those parts which come into frequent temporary contact during the working of the apparatus, viz., the end of the spring f_2 and of the screw s in fig. 369, and also the ends of the two strips in fig. 370, should be made of platinum. If this cannot be had the parts mentioned must be frequently looked after, and kept as bright as possible by the use of emery paper. For a mere demonstration of the action of the apparatus the use of platinum would be unnecessary; but if the bell is to be permanently used, it is best to solder small strips of platinum foil upon that portion of the end of f_2 which is opposite to the screw s , and similar strips must be soldered upon those portions of the two strips in fig. 370 which come into contact when the spring is pressed down. The screw s is also easily provided with a platinum point by drilling a fine hole into the end of it, and soldering a short pointed piece of thick platinum wire into the hole.

Platinum itself fuses with great difficulty, but it has the property of forming with other metals—for example, with soft solder—alloys which are comparatively very fusible. In soldering platinum care must therefore be taken not to apply too great a heat.

52. *Magnetism.*—It has been shown previously (see page 643) that one of the effects of the electrical discharge through a spiral which is coiled round a small bar or needle of steel is to render the needle magnetic; it acquires the property of attracting particles of iron. This property is not acquired temporarily, as in the case of the electro-magnets described in the preceding article,—it does not cease with the current which produced it,—but the steel bar, after the experiment, has permanently acquired the property of attracting iron. If the bar of steel is placed for a short time inside the spiral of fig. 353, and submitted to the action of the

current from two strong cells, it will become still more magnetic ; and if a somewhat thick piece of cast steel, 4 or 5^{cm} long, which has been hardened by making it red hot and then cooling it rapidly, be treated similarly it will manifest an attractive force considerably greater than that possessed by the thin needle.

A piece of hardened steel which possesses the property of attracting iron is called a 'permanent magnet,' or briefly a 'magnet.' It is assumed that the Ampèrian currents exist in hardened steel as well as in soft iron, but that a special force, to which the name *coercive force* has been given, tends to maintain the currents in the precise position which they have at any instant. It follows from this that the Ampèrian currents of a bar of steel cannot so easily assume new positions as those of soft iron, in which substance the coercive force is very feeble or from which it is almost absent ; on the other hand, if the Ampèrian currents have once been compelled to assume a position of parallelism, they maintain this position by the action of the coercive force.

A permanent magnet behaves in every respect like an electro-magnet: when freely suspended it takes up the same definite north-south position, it exhibits the same attraction between unlike and repulsion between like poles, and it acts in the same way inductively on soft iron which is brought near it.

Magnetic induction does not take place so easily in hardened steel as in soft iron. If a small piece of steel be placed in contact with either a permanent magnet or an electro-magnet, the attraction is much less than that exerted on a piece of soft iron of the same size placed in contact with the same magnet, and it will require some

time before the first piece of steel will be capable of attracting a second, and still longer before a third will be attracted by the second. But the magnetism thus manifested by the small steel bars does not disappear when they are removed from the electro-magnet; each of them is now a permanent though very feeble magnet.

A bar of steel may be made magnetic more completely and in a shorter time than by placing it simply in contact with a magnet, if the magnet, or better, electro-magnet, is moved repeatedly, and in a definite manner, along the steel bar to be magnetised. One pole of the magnet is placed upon the middle of the straight or horse-shoe bar to be magnetised, and repeatedly drawn from the middle to one end. The second pole of the magnet is then placed upon the middle, and similarly drawn to the opposite end of the bar an equal number of times; during this process, either the bar to be magnetised may be fixed and the magnet moved, or, if more convenient, the latter may be at rest and the bar moved relatively to it. In either case the magnet and bar should not be at right angles to each other, but the magnet and that portion of the bar towards which the motion is directed should form an acute angle. In fig. 371 *A*, *e* is an electro-magnet, along one pole of which the bar *s*, which is to be magnetised, is moved in the direction of the arrow; in *B*, *s* is a horse-shoe of steel, which is magnetised by drawing the permanent magnet *m* along it.

As with electro-magnets so with permanent magnets: the weight which a horse-shoe magnet can support is much more than double that which a single pole would hold.

Magnets are liable to a gradual diminution of their magnetism. To prevent this, keepers are kept in contact

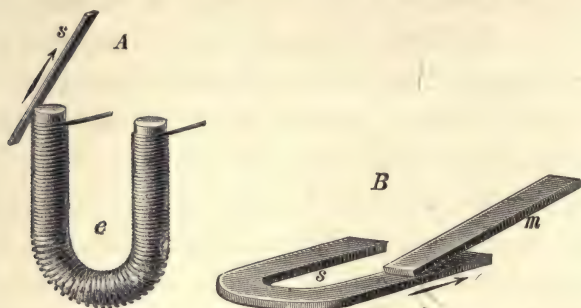


FIG. 371 (*an. proj.*).

with the poles. When the magnets are in the form of bars it is best to have a pair, arranged as in fig. 372, with opposite poles near each other, and connected on each side by keepers of soft iron.

Steel which has not been properly tempered, and cast iron, stand with reference to their magnetic



FIG. 372.

behaviour midway between hardened steel and soft wrought iron. They do not become magnetic by induction so easily as the latter, and they preserve their magnetism for some time, but not so permanently as highly tempered steel. There exists also a native ore of iron, called 'magnetic oxide of iron,' which may be rendered permanently magnetic by a current or by magnetic in-

duction. Sometimes pieces of this ore, which are already magnetic, are found in mines; they are called 'natural magnets' (or 'lodestones'). These magnets as well as 'artificial magnets,' produced by rubbing steel with natural magnets, were known long before the discovery of galvanic electricity and of the connection between electricity and magnetism.

That a freely suspended magnet takes up a definite direction may be observed by means of a small magnetised bar of steel, suspended by means of a stirrup made of paper and a fine (untwisted) thread, as shown in

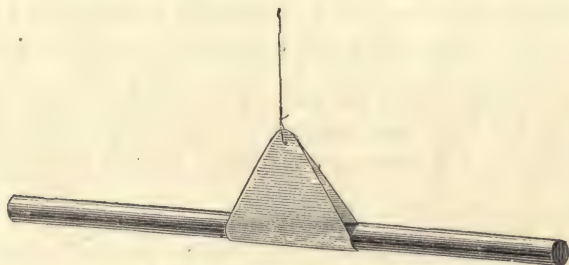


FIG. 373 (*an. proj.*; *real size*).

fig. 373; or a 'magnetic needle,' that is, a small flat piece of steel pointed at the ends so as to be lozenge-shaped, is provided with a small cap by which it can be placed upon the point of a pin as a pivot about which it is freely movable.

The little cap, a section of which is shown at *B* in fig. 374, consists usually of a small hollow cup of brass, closed at one side by a piece of agate on the lower side of which there is a shallow conical cavity; when the cavity is placed on the point, the needle is balanced in a horizontal position. The magnetic needles sold by the dealers, are often tempered blue and afterwards repolished at one end so as to distinguish the poles. In the experiments on magnetic attraction and repulsion, in order to know which poles are under observation, one end of the magnet may be marked by pasting a bit of paper upon it or coating the end with sealing-wax varnish.

One of the magnets, a small bar of steel, is suspended by the stirrup and thread (fig. 373), and the north pole is marked after the bar has come to rest in a definite position; a second magnetic bar is now suspended in the place of the first, and when it has come to rest, the like and unlike poles of the two magnets are brought successively near to one another.

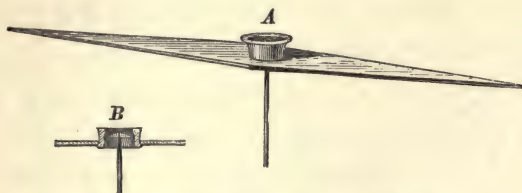


FIG. 374 (*A an. proj., A and B real size*).

A needle which balances on a pivot may be made from a piece of a thin steel knitting needle which is made red-hot but not heated too much over a charcoal fire. It is then bent into the shape shown in fig. 375, again made red-hot and thrown into water in order to temper it. It is then magnetised by being rubbed with an electro-magnet or a permanent magnet. A piece of glass tube is



FIG. 375 (*real size*).

drawn out to a point, being kept in the flame all the time, so that it may be melted off and closed at a short distance from the wider part of the tube. The closed conical end is cut off by a scratch of the file and the pressure of the fingers, heated until sealing-wax melts upon it, and when the sealing-wax is cool, the needle is heated in the middle and pressed hot upon the glass cap. The point of a darning-needle, of which the eye-end is fixed into a small piece of wood, serves as pivot. If the needle is not well balanced when placed upon the pivot, the end which dips down is ground upon the grindstone until the needle is made to swing in a horizontal position.

The fact that a freely suspended magnetised needle ultimately sets in a definite position more or less north and south, can only be explained by supposing the earth itself to be a magnet. The magnetic poles of the earth are near the terrestrial poles, but do not quite

coincide with them. Since that end of a suspended magnet which points to the north is called its north pole, the magnetic pole of the earth which is near the terrestrial north pole is magnetically a 'south' pole; but in practice it has been found more convenient to call the magnetic pole of the earth which is near the terrestrial north pole, the 'north magnetic pole' of the earth, and the opposite one, near the terrestrial south pole, the 'south magnetic pole.'

We may conclude that the definite position which a freely suspended magnet assumes, must depend chiefly on the force exerted on it by that magnetic pole which is nearest to it, and hence, since the various places on the earth are differently situated with reference to the magnetic poles, that the direction of a magnet suspended in one place will differ very considerably from that of a magnet at another place very distant from it. If a magnetic needle is freely suspended, so as to be able to set itself in its natural position, the angle between the direction in which it points and the direction of the geographical meridian of the place where the experiment is made, is called the *magnetic declination* of that place. In some parts of the globe the north pole of a magnet declines to the east of north, in others to the west of north; in the former case the declination is *easterly*, in the latter case *westerly*. In England the declination is westerly, and amounts in London to an angle of about 20° .

The magnetic poles of the earth appear to change their position on the globe in the course of time, for the position of a freely suspended magnet varies from time to time in the same place.

If a steel needle like that in fig. 375, which before magnetisation is balanced on the pivot in a horizontal position, be magnetised, the north pole will be found to incline or 'dip' downwards. The inclination would be still more considerable than it appears in this experiment, if the needle, instead of being supported in the middle of the conical cavity which lies above its centre of gravity, were supported at the centre of gravity itself. Such a needle would be in neutral equilibrium, and therefore the action of terrestrial magnetic force upon it would not be interfered with by the force of gravity. A magnetised needle which is suspended by a horizontal axis passing exactly through the centre of gravity of the needle dips in England about 68° . This angle, which the needle makes with a horizontal plane, is called the *magnetic inclination*. In the northern hemisphere of the globe a magnetic needle is nearer to the northern magnetic pole of the earth than to the southern; hence the directive action of the northern magnetic pole is greater than that of the southern, and the north pole of the needle dips. It follows that in the southern hemisphere the south pole of the needle dips; that the inclination is greater the nearer a needle is to either of the magnetic poles of the earth; and further, that between the northern and southern magnetic poles there must be a line round the globe, at any point of which both poles of the needle are equally acted upon by the magnetic poles of the earth, and where the needle is therefore horizontal. This line is called the 'magnetic equator.' The magnetic equator does not coincide with the terrestrial equator; it is, however, pretty near to it, and crosses it in several points.

It is extremely difficult to prepare a needle which before magnetisation will rest in neutral equilibrium, and the measurement of the angle of inclination requires very delicately constructed, expensive instruments. For merely observing the dipping of the north pole, a knitting-needle should be suspended by a thread tied round its middle and adjusted until it swings horizontally. The knot should be fixed with a little bee's-wax, to prevent it from shifting while the needle is magnetised. After magnetisation it will assume a considerably inclined position, although the angle of inclination is of course sensibly smaller than that at which a needle would incline which was suspended exactly at its centre of gravity.

If the earth is a magnet it should be capable of acting inductively upon soft iron. A bar of soft iron becomes, indeed, feebly magnetic if it is held in the same position which a freely suspended magnetic needle assumes under the influence of the magnetism of the earth, that is, if held in the approximate north-south direction of such a needle, and at the same time so as to be inclined to a horizontal plane at an angle of about 68° . The end of the bar which dips becomes a north pole, the upper end becomes a south pole, as can be proved by bringing the poles of a small magnet near the end of the soft iron bar. The lower end repels the north pole of the magnet, the upper end repels the south pole.

The longer and thicker the bar of soft iron, the more apparent becomes its magnetisation by the inductive action of the earth. The experiment is best made with a bar 0.5 to 1^m long, and 2 or 3^{cm} thick; if such a bar cannot be obtained, a small iron rod of the size of a somewhat large pencil may be used. The bar must be heated and then allowed to cool very slowly, so as to be as soft as possible. For testing the magnetisation of the bar and the distribution of its magnetism, a very small feebly magnetic needle must be used; otherwise the test-magnet itself acts inductively on the bar, and attraction would take place in any case. As test magnet a needle bent like that in fig. 375, but without cap and pivot, tied to a piece of untwisted thread, should be used; a magnet which swings on a pivot cannot be well used for the purpose, because in the position in

which the bar must be held for magnetisation its raised end cannot be well brought near the south pole of the test magnet even if the support upon which it swings is placed near the edge of the table. If an iron bar is to be used again for the same experiment, it should not be used for any other purpose, and must be kept in a horizontal position, one end pointing a little to the north of east, the other a little to the south of west, that is in a direction at right angles to the position of a freely suspended magnet. Any piece of iron or steel which is kept for a time in such a position that one end of it points more to one of the magnetic poles of the earth than the other end, acquires a feeble permanent magnetism, especially if the piece of steel or iron has been at the same time subject to mechanical concussion of its particles by blows, twists, etc.; it is in this way that magnetism is frequently developed in steel and iron instruments, tools, lightning conductors, etc.

The iron bar used for the experiment on the inductive action of the earth must obviously be quite free from every kind of magnetism. It should be placed horizontally in the approximate east-west direction previously described, and either pole of a small magnetic needle should be successively brought near each end of the bar; if in each of these four trials, attraction takes place uniformly, the bar is free from magnetism.

If the current of a galvanic battery passes near to a freely movable magnetic needle, the needle is deflected from its former position, unless the direction of the current is the same as that of those portions of the Ampèrian currents of the needle which are nearest to the current. The deflection is the greater the more intense the current, and with a very strong current the needle may even assume a position almost at right angles to its original north-south direction. If the wire through which the current passes is above the magnetic needle, and the current flows from north to south, the north end of the needle is deflected towards the east.

The direction in which the north pole of the needle is deflected depends on the relative positions of the needle and the wire through which the current flows,

and also on the direction of the current itself. The following rule is generally given to assist the memory in determining the various deflections of the needle under the influence of a current. If we imagine an observer placed in the conducting wire in such a manner that the current entering by his feet issues by his head, and that his face is always turned towards the needle, the north pole of the needle is always deflected towards his left hand.

The student should prepare a small cylinder of wood, which may represent the needle, and after drawing round the surface several circles with arrow-heads to indicate the direction of the Ampèrian currents, and marking the two ends *correctly* N and S (see fig. 356) to distinguish the poles, then the direction in which a needle is deflected in any given case may be found by simply holding the little cylinder in such a manner that the Ampèrian currents drawn upon it have the same direction as the current in the wire. The position of a magnetic needle would in fact be exactly the same as that of the small wooden cylinder, if the needle were not influenced by the action of the magnetism of the earth, in addition to the action of the current. In consequence of this the needle would, however, take up a position *intermediate* between its natural north-south position and that indicated by the wooden cylinder.

A very weak current may produce a considerable deflection if an 'astatic' system of two needles, fig. 376, be used. Two magnetic needles, $n_1 s_1$ and $n_2 s_2$, as nearly equal as possible, are rigidly connected in such a manner that their poles are turned opposite ways. If the magnetism of one needle were exactly equal to that of the other, the earth would not exert any directive

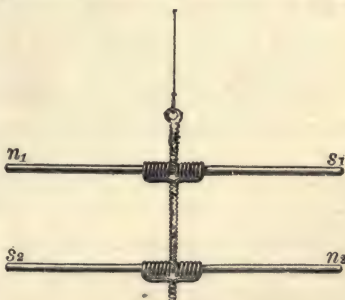


FIG. 376 (*real size*).

action upon them, because the force exerted on one needle would be neutralised by the equal opposite force exerted on the other, and the system would consequently rest indifferently in any direction. But such an equality of both needles cannot be obtained, one is always a little more strongly magnetised than the other; hence the system obeys a directive force which is equal to the difference of the directive forces exerted upon the separate needles, and is therefore extremely small. The consequence of this is that a feeble current passed either above the upper needle or beneath the lower one, is sufficient to deflect the system considerably. The deflection is still greater if the current is made to pass *between* the needles, for then the action of the current upon the system is increased, both needles being urged to turn in the same direction, as follows from the rule stated previously.

An astatic needle may be made of two pieces of a knitting needle of equal length, which are magnetised by drawing the poles of a magnet along each needle in the way previously described, doing it the same number of times for each needle; they are then connected by means of thin copper wire as shown in fig. 376. The system is suspended by a silk fibre, or by a fine silk thread. When the magnetism of both needles is nearly equal, and they are not fixed *exactly* parallel, the system assumes a position which somewhat differs from the correct approximate north-south position, but this does not interfere at all with the experiments on the deflection. The wire through which the current passes cannot be placed exactly between the two needles so as to be in the same plane with them, as the wire which connects them is in the way; the current should be brought within 1 or 2^{mm} from the wire. One Bunsen or Grove element is sufficient to produce a distinct deflection of a common magnetic needle; for an astatic needle the current of one Meidinger cell is amply sufficient.

By means of astatic needles the presence of exceedingly feeble currents may be detected, if the con-

ducting wire is repeatedly carried first between the two needles and then back again beneath the lower needle, so that the deflecting action of the same current upon the needles is multiplied many times. An instrument of this kind is called a *Multiplier* or 'Galvanometer.' A very simple multiplier with 10 coils of stout covered copper wire is represented in fig. 377. It may be

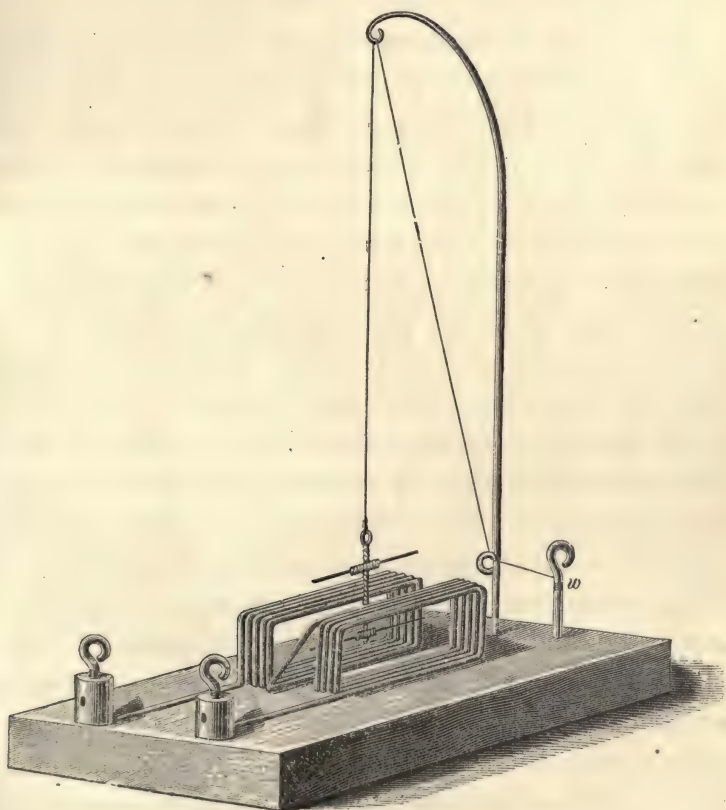


FIG. 377 (*an. proj.*; $\frac{2}{3}$ real size).

easily constructed, and will distinctly show the current produced by *one* cell of the small battery, fig. 336.

The arrangement of the parts of this apparatus and its construc-

tion will be easily understood from the figure without further explanation. The silk thread by which the astatic needle is suspended is drawn through two rings in the wire which supports it, and wound round a pin *w*, which is movable with considerable friction within a hole in the wooden base of the instrument. By turning *w* one way or the other, the suspension thread may be raised or lowered and the astatic needle adjusted to the proper height. The whole should be protected against currents of air by a bell jar, or a glass bottle from which the bottom has been removed, the binding screws being left outside the cover.

The larger instruments of this kind, such as are used in many scientific investigations, have coils which consist of a great many turns of much finer wire. Such fine wire could not be coiled without support as in the apparatus fig. 377, but it is generally coiled on two separate frames placed one on each side of the astatic needle. By means of such instruments, consisting of several thousand turns of wire the presence of currents may be detected which are incomparably weaker than those observed in the preceding experiments.

53. *Induction of currents.*—Under certain circumstances the current which traverses a conductor may develop a second current in a conductor near it, through which no current was passing previous to the action of the first current. This class of effects of a current is comprised under the name ‘current-induction.’ The investigation of the laws of current-induction, and their experimental demonstration, require rather complicated apparatus, and it will be sufficient in this work simply to state these laws, and to describe an apparatus the action of which depends upon them. The laws are the following:—

I. *A current which begins, a current which approaches, a current which increases in strength from any cause, in-*

duces an *INVERSE* momentary current in a neighbouring conducting circuit.

II. A current which ceases, a current which recedes, or a current which decreases in strength from any cause, induces a *DIRECT* momentary current in a neighbouring circuit.

The 'induced' current has not the same duration as the 'inducing' current; it lasts only as long as the change lasts which the inducing current undergoes. If the circuit is closed or broken, the duration of the induced current is exceedingly short; it is somewhat longer when the induced current is developed by gradual changes in the relative position of the two conductors. As long as the distance between two circuits is the same, and one is traversed by a continuous current of constant strength, no current is induced in the adjacent conductor.

In order to produce by induction currents of sufficient intensity to be rendered manifest without specially delicate instruments, two spiral coils of wire are used as conductors, one of which is within the other. In such an arrangement, each turn of one coil acts upon all neighbouring turns in the other coil, and a much greater effect is thereby obtained than would be produced if two wires were stretched side by side, so that any portion of one wire could act inductively only upon an equal length of the other.

The coil through which the inducing current of the battery passes is called the *primary coil*, the current itself the *primary current*. The second coil, in which the induced current is developed, is termed the *secondary coil*, the current itself the *secondary current*. The

secondary coil is usually the larger of the two and surrounds the primary.

If the primary coil is connected with a battery and the circuit closed, an instantaneous current will be produced in the secondary coil at the moment of closing the circuit, and the direction of the secondary current will be *inverse* to that in the primary coil, that is, it will be in a contrary direction. Again, at the moment when the circuit of the primary current is opened there is another instantaneous current developed in the secondary coil, but it is *direct*, that is, it flows in the same direction as the inducing current.

The inductive power of the primary coil is immensely increased by putting a bar of soft iron in the heart of it. The Ampèrian currents of the bar of iron, which have previous to the closing of the primary circuit all possible directions, assume parallel positions at the moment of closing the primary current and the same direction as that of the current itself, while at the moment of breaking the primary current they all return to their original irregular positions. It follows that at the instant at which a current begins in the primary coil, a current is also set up in the iron core, because the Ampèrian currents are now parallel, and again, that at the instant when the current stops in the primary coil a current is made to stop in the core, because the Ampèrian currents return to irregular positions. Another current which undergoes simultaneously the same changes is thus superadded to the primary current, and the effect is therefore considerably increased. The action becomes still more strengthened if instead of the bar a bundle of soft iron wires is used.

A permanent magnet acts quite similarly to a primary coil, and apparatus are constructed in which an induced current is developed solely by the inductive action of Ampèrian currents. Apparatus of this kind are called 'magneto-electrical.' A bar of soft iron is surrounded by a spiral in which a current is to be induced; a permanent magnet is made to approach and to recede alternately, and the position of the Ampèrian currents of the soft iron bar is thus alternately rendered parallel and again irregular. The effect is perfectly analogous to the closing and opening

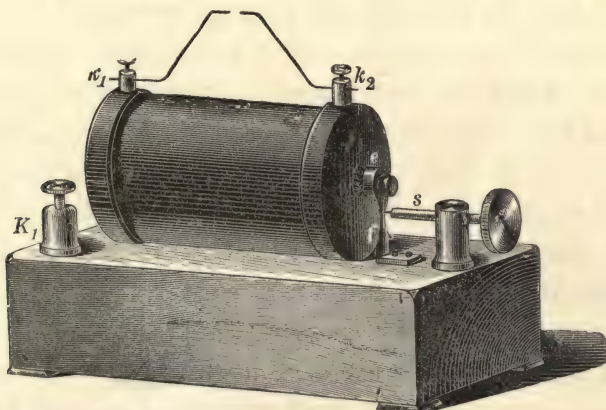


FIG. 378 (*an. proj.*; *real size*).

of the circuit in a primary coil, and a secondary current is induced in accordance with the laws enunciated previously.

Fig. 378 shows a small apparatus, or so-called *induction coil*, for conveniently developing powerful induced currents. A rectangular block of wood supports a bobbin, the ends of which are formed by round discs of black polished wood, or ebonite. In the centre of the bobbin is a bundle of soft iron wires. The primary or

inducing wire is made of moderately thick insulated copper wire ; it is coiled in several layers round the bundle of iron wire. On this primary wire is coiled the secondary wire, which is also of copper, but is much finer and longer so as to form as many turns as possible. This coil of fine wire is usually protected by a covering of some stout fabric. The ends of the secondary wire lead to the binding-screws k_1 and k_2 . The terminals of the battery are clamped in the binding-screws K_1 and K_2 , of which the former only is seen in the figure. The clamp K_1 is immediately connected with one end of the primary coil ; the other end of this coil is in metallic connection with the small spring f which carries on the top, just opposite to the projecting bundle of iron wire, a small piece of iron e . Upon f , exactly opposite to the point of the screw s , is soldered a small piece of platinum foil ; this is in contact with the end of the screw s , which is also tipped with platinum. The small upright of brass which carries the screw s is in conducting connection with the binding-screw K_2 . The connecting wires are all hidden in the wooden base of the apparatus, which further contains a special contrivance, interposed in the primary circuit and calculated to increase considerably the intensity of the induced currents, called the 'condenser.' For the theory of its action the student must consult larger works, as also for the explanation of the more intense inductive action of a bundle of iron wires compared with that of a massive bar of soft iron.

When K_1 and K_2 are connected with the poles of a battery of sufficient strength, the current passes through the primary coil, and the bundle of iron wire becomes

magnetic; the piece of iron e is attracted by it, the contact between f and the point of s ceases, the circuit is opened, and the bundle again loses its magnetism. The piece e is then brought back to its former position by the spring f , the circuit is again closed, the bundle becomes magnetic, and this action is repeated in rapid succession, as long as K_1 and K_2 are connected with the battery. The rapid motion to and fro of f and e causes a buzzing sound; and if the primary current is sufficiently intense small sparks are seen at the point where contact is broken. Induced currents, alternately in opposite directions, are produced in the secondary coil at each making and breaking of contact.

Induced currents are of very short duration, but possess considerable tension, and traverse inferior conductors far more easily than the primary currents produced by the battery itself. Their effects upon the human body are very powerful. If two copper wires with handles of metal be clamped in the binding-screws k_1 and k_2 , and the handles are held in the hands, a succession of shocks will be felt, due to the continuous renewal of the induced current.

One Meidinger element is capable of setting the apparatus, fig. 378, in activity and of producing sensible effects. In using so weak an element the screw s must be accurately adjusted, that the point may touch the spring as gently as possible. Before seizing the handles the hands should be slightly moistened, in order to increase the conductivity of the skin. When the coil is worked with a Grove or Bunsen cell the effect is very sensible, even if the hands are dry. Persons who are rather sensitive to electric shocks should fill the cell only to about one-fourth with acid, or the sensation may be unpleasantly strong. Strong currents produce spasmodic contractions of the muscles, and a powerful effort is often required to open the hands and release the handles.

The handles are made of two rectangular pieces of sheet zinc or

brass, 10 or 12^{cm} long and 7 or 8^{cm} wide; they are hammered round with the mallet upon a circular bar of wood, so as to form cylinders of the stated length and about 2 or 2^{cm}·5 in diameter; the sides which meet need not be joined by solder. The covering is removed at both ends from two pieces of copper wire, 0·5 or 1^m long and 0^{mm}·6 thick, and each wire is soldered with one end into the inside of one of the handles; the other ends are soldered to stouter pieces of copper-wire, about 2^{cm} long and 1^{mm} thick, by which they are clamped to the binding screws K_1 and K_2 .

If the primary current is that of two strong Grove or Bunsen cells the induced currents are so powerful as to pass through the non-conducting air. Two wires of copper, brass, or iron, 1^{mm} thick, are bent as shown in fig. 378, and fixed in the clamps k_1 and k_2 ; when the distance between the opposite ends is not more than 1 or 2^{mm} sparks are seen to pass between the ends.

An apparatus double the size of that assumed in fig. 378 gives sparks as long as from 6 to 10^{mm}. The spark of the induction coil produces the same effects as the spark accompanying the discharge of frictional electricity. Even the spark of the apparatus fig. 378 is sufficient to ignite gas; for igniting ether, or the mixture of potassic chlorate and sulphide of antimony, and perforating paper, a coil of about double the size is required. With larger coils, which give sparks of from 6 to 60^{cm} in length, glass plates several centimetres thick may be perforated, paper or wood ignited, and various other remarkable effects obtained.

Induction coils even of the small size above described are especially convenient for exhibiting the beautiful appearances of the electric light in the rarefied space of Geissler's tubes (compare page 638). The two ends of platinum wire which project from a Geissler's tube are connected with the clamps k_1 and k_2 ; when the coil is joined to the battery a beautiful luminous trail is seen inside the tube, which appears to be constant, but consists in reality of successive flashes of electric light which only last as long as each induced

current lasts; but by the law of persistence of visual impressions the luminosity appears to be continuous. This may easily be shown by the revolving mirror, fig. 235 (page 397). If the tube is placed vertically and its reflected image is observed in the rotating box, a series of separated images of the electric light in the tube will make its appearance.

Geissler's tubes, containing different gases in a state of great rarefaction, and having their central portions straight and very narrow, are also used for studying the spectra of incandescent gases.

The tube is placed in a vertical position before the slit of the spectroscope; or it may be simply viewed through the prism, at a distance of about 1^m from it, the whole being adjusted precisely as in the experiments on the coloured hydrogen flames described previously (see page 491). The wider portions of the tube at both ends, which are less luminous, give a faint indistinct spectrum; but the central part, which forms a bright luminous line, produces a sharply defined spectrum consisting of single lines, which are images of the tube. Thus, if the tube is filled with rarefied hydrogen, three lines are seen, a red, a green, and a blue. The spectra of other gases are generally much more complex.

HEAT.

54. *Expansion by heat. The Thermometer.*—An object which is brought in contact with the external surface of the human body generally produces sensations of two kinds. Besides the sensation caused by the pressure of the object against our body, we experience others which induce us to characterise the object as being cold, warm, hot, etc. The particular character of these sensations is attributed by us to the particular state, in relation to *temperature*, of the object which gives rise to them,—thus, if the object feels to us ‘hot,’ we say that it has a ‘high temperature;’ if it feels ‘cold,’ we say that it has a ‘low temperature,’—while to the common cause of all these sensations, and of many other connected phenomena, the name *Heat* is given.

Physicists have arrived in recent times at tolerably definite conclusions with reference to the nature of heat. To enter befittingly upon this subject would exceed the limits of this work, and it will therefore be our principal aim to study the various effects of heat upon matter. Of these *expansion* is the first to be noticed, because this effect affords a means of measuring temperature.

In fig. 379 *a b c d* represents a bent piece of brass wire, so constructed that the straight bar *e f* exactly fits into the space between the ends *a* and *d*. The piece *a b c d* is held between *c* and *d* with the flat pliers or

the crucible tongs in the outer portion of the flame of a spirit lamp or Bunsen's burner, so that the piece bc may become as hot as possible, while the piece ef is very little heated; then, as soon as bc is sufficiently hot, the piece ef drops out of the frame, although it was very firmly fixed previous to the heating. It follows that the heated portion of the wire has expanded. If the piece ef is held in its place between a and d , allowing it to rest upon the end d , an exceedingly small gap will be seen between a and e ; the expansion of brass by heat must hence be very inconsiderable. Finally, if the piece $abcd$ be again cooled by immersing it in water, it will clasp the bar ef as firmly as before the heating; it follows that the wire has contracted again by being cooled.



FIG. 379
($\frac{1}{2}$ real size).

All solid bodies behave like the brass wire in the preceding experiment: they expand when their temperature is raised, and contract when their temperature is lowered. Some substances expand more, many others much less, than brass.

If a test-tube, 15 or 18^{cm} long, be filled with paraffine oil to about 3^{cm} from the edge and heated, the liquid rises in the tube 1 or 2^{cm}; when the tube is cooled the liquid contracts again, just as the brass did in the preceding experiment. Most liquids do not expand so much as paraffine oil; but in all liquids the expansion caused by heat is greater than in solid bodies.

A retort or a flask is clamped in the fork of the retort-stand, the mouth downwards, and dipping a

few millimetres below the surface of the water in a small saucer, as in fig. 380.

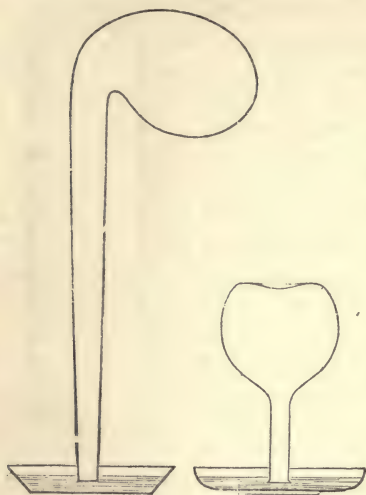


FIG. 380 ($\frac{1}{8}$ real size).

If the hand be placed upon the wider portion of either vessel, the heat of the hand is sufficient to cause a perceptible expansion of the air within the vessel. If a spirit or gas flame be used for heating the vessel, the expansion of the air will be so considerable that a large quantity of air will escape through the water in the form of bubbles; when

the flame is withdrawn and the vessel allowed to cool the air within it contracts again, and, in consequence of the atmospheric pressure outside, the water rises to some height in the neck of the vessel. The expansion and contraction of air, which is heated or cooled respectively, may be very strikingly shown by clamping the contrivance represented in fig. 168 (page 244) horizontally in the retort-stand, and applying the heat of a flame to the portion of the tube which contains air; the mercury will be pushed towards the opening of the tube as the air expands, and will recede again when the air is allowed to cool.

The brass piece, fig. 379, is made of wire, 6^{mm} thick, which is softened over a charcoal fire and hammered into the required shape with the mallet, the wire being either clamped in the jaws of the vice or placed upon one of the beaks. The short ends *a* and *d* must be bent first, and the two sides, which are horizontal in the figure, afterwards. The extremities of *a* and *d*, and also those of the bar

ef, should be filed very smooth, and slightly but uniformly convex, as indicated in the figure.

The heating of the vessel with the paraffine oil must be done very cautiously, as the glass is apt to crack, and very serious accidents might be caused if the paraffine, which is very inflammable, were to take fire. The safest way is not to heat the vessel by means of a lamp, but by immersing it in a pot containing hot water. The expansion is still better observable if a small flask with a narrow neck is filled with the liquid, so that it only just fills the wide portion of the flask up to the neck, and the flask is heated. In this experiment, however, it is better to use spirits of wine instead of paraffine oil, because the latter cannot well be entirely removed from the interior of a vessel without rubbing off the adhering drops with a piece of cloth or blotting-paper, which is impossible with a small flask. The spirits of wine should also be heated with great caution, and not too strongly. Water expands less than either paraffine oil or spirits of wine. If the experiment is to be made with water, the flask, about 6 or 8^{cm} wide, should be closed by a well-fitting cork, perforated for receiving a glass tube, 3^{mm} wide, and 20 or 30^{cm} long. Common water always contains a quantity of air in solution, and when heated the air escapes in bubbles; the water used for the experiment should therefore be first boiled, and then allowed to become cool again. The flask is filled up to the neck, so that no air may remain in the neck when the mouth is closed by the cork; if the water rises too high in the tube, some of it may be removed by sucking through a straw, which is introduced into the tube, until the water stands a few centimetres above the cork. The heating in this experiment also is best done by immersing the flask in hot water. At first, as soon as heat is applied, the water seems to contract, for it falls a little in the tube; but the cause of this is that the sides of the vessel are heated first, before the heat reaches the water. The vessel therefore becomes of somewhat greater capacity than it was previously, while the water really preserves its original volume, and cannot reach up to the previous height in the larger vessel; hence it falls at first. As soon as the heat reaches the water itself it begins to expand, and rises in the tube.

The only precautions necessary in the experiment on the expansion of air are to avoid the heating of the neck of the vessel, otherwise it is apt to crack when the water rises in the neck after the flame is withdrawn; and further, not to hold the flame in one place under the vessel, but to carry it constantly round and round, so that the heat may be applied uniformly and slowly.

The instruments for measuring temperatures called 'thermometers' depend on the expansion of liquids by heat. Solid bodies are not suited for thermometers, because their expansion is too small, and therefore the change of volume, due to a given change of temperature, cannot be easily observed. Gaseous bodies, on the other hand, are unsuitable for thermometers, especially those for common use, partly because they expand too much, partly because their volume depends not only on their temperature but also on the pressure of the atmosphere, which, as we know, is constantly varying. In far the greater number of thermometers, mercury is the liquid used. This liquid is preferable to most others, on account of various properties which mercury possesses. It very soon takes the temperature of surrounding bodies, because heat passes very easily in and out of mercury, and hence it indicates rapidly whatever changes of temperature take place; it also expands regularly in proportion to the temperature, that is, a double or treble increase of temperature causes a double or treble expansion, and so on; its opacity allows of its being easily seen when contained in very narrow glass tubes; it does not wet glass, hence, when the surface of mercury falls in a glass tube, nothing is left adhering to the sides of the tube; finally, it is capable of passing through a long range of temperature without changing its state of aggregation, for it boils at a temperature which is higher than the fusing point of lead, while it does not freeze in the greatest winter cold observable in Central and Western Europe. At a very low temperature, such as may be observed in higher

latitudes, or as can be produced artificially, it freezes, and is consequently no longer available for indicating changes of temperature. For such low temperatures a thermometer filled with alcohol must be used, for alcohol does not freeze at any temperature hitherto observed.

A thermometer consists of a stem formed of a capillary glass tube with thick sides, at the end of which a cylindrical or spherical bulb, with very thin sides, is blown. The bulb and a part of the stem are filled with mercury, the remaining space within the stem being a vacuum. The expansion is measured on a scale, graduated either on the stem itself or on a frame of wood, glass, or metal, to which the stem is attached. In thermometers which are used for liquids the stem and scale are generally either surrounded by an outer tube, which is fused below to the bulb, as *A* and *B* in fig. 381, the scale being graduated on a strip of paper or on white glass, or the stem is made thicker than the diameter of the bulb, and the scale is engraved on the stem itself, as in *C* and *D* of fig. 381. Thermometers of the latter form are frequently used in physical experiments, because they can be easily introduced into narrow

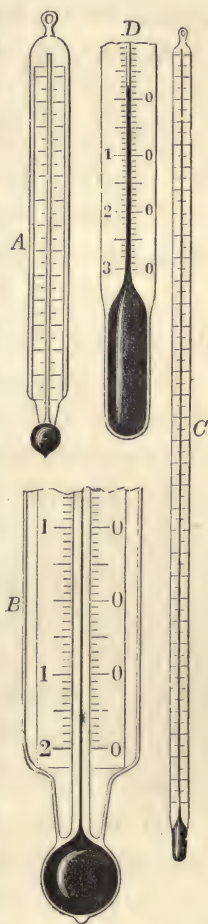


FIG. 381
(*A*, *C*, $\frac{1}{3}$ real size;
B, *D*, real size).

openings of vessels or pushed through corks, by which vessels or flasks are closed. For our experiments one or two of this kind will be the most suitable.

On the scale of each thermometer two fixed points are marked first. These are the *freezing point* and the *boiling point* of water. The distance between these two points is divided into a definite number of equal parts, called 'degrees.' On the Continent, and more especially in France, this space is divided into 100 parts, and this division is called the *Centigrade*, or, from its inventor, the *Celsius* scale. The Centigrade thermometer is now almost exclusively adopted for scientific purposes, and will be used in this work. On this scale the freezing point of water is denoted by zero, and called 0° ; the boiling point is called 100° ; the space between the fixed points is divided into 100 parts of equal capacity, and the division is carried on through the length of the scale below 0° and above 100° . To indicate temperatures below zero a minus sign ($-$) is placed before the corresponding figures; thus -5° signifies 5 degrees below zero, or, as it is often expressed (though incorrectly), 'five degrees of cold.'

In Germany Réaumur's scale is still used for many ordinary purposes. The freezing point is denoted by 0° , as in the Centigrade scale, but the boiling point is marked 80° , and the distance between these points is divided into 80° instead of into 100° ; that is to say, 80 degrees Réaumur are equal to 100 degrees Centigrade.

One degree Réaumur is thus equal to $\frac{100}{80} = \frac{5}{4}$ of a degree Centigrade, and one degree Centigrade is equal to $\frac{80}{100} = \frac{4}{5}$ of a degree Réaumur; or, as usually stated,

$1^{\circ} \text{ R.} = \frac{5^{\circ}}{4} \text{ C.}$, and $1^{\circ} \text{ C.} = \frac{4^{\circ}}{5} \text{ R.}$ Consequently, to convert any number of degrees Réaumur into Centigrade degrees it is merely necessary to multiply them by $\frac{5}{4}$; similarly, if a number of Centigrade degrees is multiplied by $\frac{4}{5}$, we obtain the corresponding temperature in Réaumur degrees. For example, $28^{\circ} \text{ R.} = 28 \times \frac{5^{\circ}}{4} \text{ C.} = 35^{\circ} \text{ C.}$; $-30^{\circ} \text{ C.} = -30 \times \frac{4^{\circ}}{5} \text{ R.} = -24^{\circ} \text{ R.}$

In England, and also in Holland and North America, the thermometer scale invented by *Fahrenheit* is still much used. In this scale the freezing point of water is called 32° , and the boiling point 212° , the intermediate space being thus divided into 180 equal parts. The zero point of Fahrenheit's scale corresponds to $-17^{\circ}77 \text{ C.}$ and $-14^{\circ}22 \text{ R.}$

To convert a certain number of Fahrenheit degrees into Centigrade or Réaumur the number 32 must first be subtracted from the given number, in order that the degrees may count from the same point on the scale, and the remainder is then multiplied by $\frac{4}{9}$ to convert into Réaumur degrees, and by $\frac{5}{9}$ to convert into Centigrade degrees. Thus $149^{\circ} \text{ F.} = (149 - 32) \frac{4^{\circ}}{9} \text{ R.} = 117 \times \frac{4^{\circ}}{9} \text{ R.} = 52^{\circ} \text{ R.}$; again, $149^{\circ} \text{ F.} = 117 \times \frac{5^{\circ}}{9} \text{ C.} = 65 \text{ C.}$ Similarly, $-4^{\circ} \text{ F.} = -36 \times \frac{4^{\circ}}{9} \text{ R.} = -16^{\circ} \text{ R.}$;

or $= -36 \times \frac{5^\circ}{9} = -20^\circ \text{ C.}$ To convert Réaumur or Centigrade degrees into Fahrenheit degrees, their number is multiplied by $\frac{9}{4}$ or $\frac{9}{5}$ respectively, and 32 is then added to the product; for example, 12° R.
 $= 12 \times \frac{9}{4} + 32 = 27 + 32 = 59^\circ \text{ F.}; -25^\circ \text{ C.}$
 $= -25 \times \frac{9}{5} + 32 = -45 + 32 = -17^\circ \text{ F.}; -5^\circ \text{ C.}$
 $= -5 \times \frac{9}{5} + 32 = -9 + 32 = 23^\circ \text{ F.}$

The correct determination of the two fixed points of a thermometer requires various important precautions, and if a thermometer has been purchased of a dealer, it is in all cases necessary to repeat the determination, in order to test the accuracy of the scale. In order to determine the lower fixed point, a vessel is nearly filled with snow or pounded ice and the thermometer immersed in it in a vertical position, so that the snow or ice reaches very nearly up to the point marked with zero on the scale. The snow or ice is cautiously stirred with a splinter of wood, and the point is observed at which the top of the thread of mercury remains stationary.

If the determination of the freezing point is made in the summer, and the ice is obtained from an ice-well, the mercury of the thermometer falls at first rapidly, then more and more slowly, and finally it remains stationary until a great portion of the ice is melted. The same happens if the experiment is made in the winter on a day when the temperature of the air is not

too cold and the ice has been brought into the room out of the open air. If the water containing the melting pieces of ice be briskly stirred, the top of the mercury will remain stationary as long as there is a very small portion of ice left in the vessel. But if the ice or snow be obtained from the open air during a severe frost, the mercury of the thermometer falls at first to the temperature of the mass of ice, which is below the freezing point of water, and as the ice becomes gradually heated by contact with the warm air of the room, the mercury slowly rises and becomes finally stationary when the ice begins to melt. Properly speaking, therefore, the temperature which is determined by the experiment is that at which ice melts, not that at which water freezes. It will, however, be seen farther on that these two temperatures are identical.

If the scale of a thermometer is correct, the mercury should remain stationary at 0° , when it is immersed in melting ice; if this is not the case, the difference should be noted, and must hereafter be applied as a correction when the thermometer is used for indicating temperatures.

For the determination of the freezing point it is best and most convenient to use snow; if it cannot be had, and the ice obtained is in large lumps, it should be broken into very small pieces with a strong knife, which is used as if it were intended to cut thin slices off the mass, or it may be crushed with the hammer. This is best done by putting the ice upon a board, placing another board on the ice, and striking with the hammer on the upper board; still, the upper board will not altogether prevent many pieces from flying about. This may be almost completely prevented by loosely wrapping the ice to be crushed in a piece of strong cloth; but the cloth is easily torn by the sharp edges of the broken pieces.

For determining the boiling point a flask with a long

neck may be used, such as that represented in fig. 382. The flask is about half-filled with water, and the thermometer is suspended in the flask, either by being tied to a thin bar of wood which is placed across the mouth of the flask, or it may be clamped in the retort-stand, if the stem is sufficiently long. The bulb of the thermometer should in any case not dip into the water it-

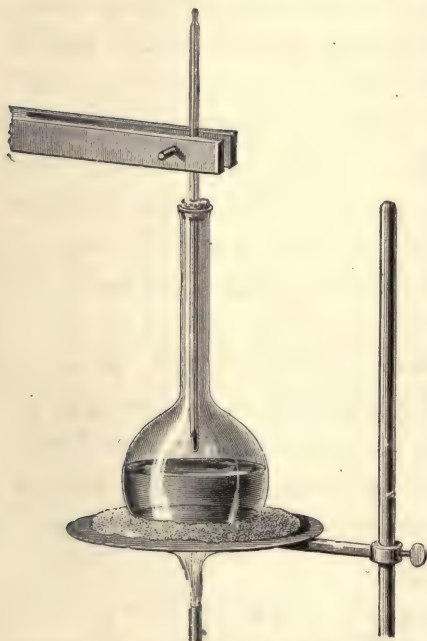


FIG. 382 (*an. proj.*; $\frac{1}{2}$ real size).

self, for the temperature of boiling water is not strictly constant, but varies slightly under different circumstances; whereas the temperature of the steam produced by boiling water is invariable, if the pressure of the atmosphere is constant. Care must, however, be taken that the evolution of steam is pretty brisk, and that the generated steam is not farther heated by contact with the hot sides

of the glass vessel. This may be prevented by supporting the flask upon a thin plate of metal with a circular aperture; the heated air is by this means forced to flow off in all directions, and is not allowed to ascend close to the sides of the vessel. To prevent the metal itself from becoming too hot it is covered almost to the edge with a layer of sand, 1 or 2^{cm} high, all round the flask.

The mouth of the flask is lightly closed with a loose piece of cotton-wool, which prevents the external air from entering the flask and cooling the steam within. As long as the interior of the neck of the flask appears cloudy the steam has not obtained the requisite temperature, for the cloudiness is due to condensed steam, that is, to moisture. Steam itself is transparent and as invisible as air ; when it comes in contact with cooler air it is condensed to very small drops of water, and has then the appearance of 'fog.'

The boiling point of water, or rather the temperature of steam produced by boiling water, is not so absolutely constant as that of the freezing point, but depends on the pressure of the atmosphere ; the less the atmospheric pressure, the lower is the temperature of the boiling point ; and the greater the atmospheric pressure, the higher is the temperature of the boiling point. A correct thermometer immersed in steam arising from boiling water should indicate a temperature of 100° C., when the pressure of the atmosphere at the time and place where the experiment is made is equal to that of a column of mercury 760^{mm} high. This temperature of 100° C. is taken as *the normal boiling point of water*. In localities which are situated several hundred metres above the level of the sea, the atmospheric pressure is never so great as that mentioned, and in other places it is scarcely ever exactly equal to it at the precise time when the boiling point is determined. Hence it is necessary to know to what extent the boiling point varies, when the pressure of the atmosphere differs from the normal pressure. If the pressure indicated by the barometer is not higher than 780^{mm} nor lower than

700^{mm}, the boiling point is raised or lowered by nearly $0^{\circ}\cdot0375$ for each millimetre which the barometer stands respectively above or below the normal pressure. For example, if the barometer stands at 740^{mm}, that is, 20^{mm} below the normal pressure; then the temperature of the boiling point is $20 \times 0^{\circ}\cdot0375 = 0^{\circ}\cdot75$ below 100° , and a correct thermometer should indicate a temperature of $99^{\circ}\cdot25$.

It follows, that in examining the correctness of the boiling point on the scale of a thermometer the barometer should be read at the same time, and the true boiling point at the observed pressure should be calculated as in the preceding example. If the top of the mercury becomes stationary at the temperature found by the calculation, no error has been committed in marking the boiling point, but if a difference is observed it must be noted and applied as a correction to the readings of the instrument.

The aperture in the metal plate for supporting the flask used in the determination of the boiling point should be just wide enough to admit the lower part of the flask, up to nearly half its height; the ring of metal left should be at least 6^{cm} wide. It may be cut out of a piece of sheet-iron or brass (zinc would melt) by drawing two concentric circles on the metal, cutting along the outer circle with the shears and with the chisel along the inner, and finally smoothing the inner edge, so that the sides of the flask may be everywhere in close contact with the metal and no projecting points may be left which might injure the flask. If larger glass vessels are to be heated it is advisable to place underneath them a piece of wire gauze, which is bent so as to adapt it as nearly as possible to the shape of the lower portion of the glass vessel. By means of such gauze the heat is distributed more uniformly around the vessel than it would be without it, and the cracking of the glass is prevented. Gauze of brass wire is better for the purpose than iron gauze, which is much sooner destroyed by the heat; brass gauze is also more pliable, especially when it has been gently heated. For heating larger vessels over a Bunsen burner it is best to purchase a special support, like

that represented in fig. 383. Such stands are usually sold with plain and toothed rings of different sizes, so as to be used in operations and experiments in which vessels are to be heated for various purposes. The spirit lamp represented in fig. 16 (p. 15) is provided with a support suitable for the present experiment. If the student cannot procure one, he should clamp the neck of the flask in the fork of the retort-stand, previously placing weights upon the foot of the stand to prevent it from being overturned by the weight of the flask. Three small holes are made near the edge of the ring of metal, the ring placed round the lower part of the flask, and kept in position by three pieces of wire, each bent at both ends, so as to fit into a hole of the ring at one end, while the other end is suspended over the edge of the mouth of the flask.

It is frequently found, in testing thermometers, that both fixed points are higher than marked on the scale. This displacement arises from the contraction of the bulb after the thermometer has been graduated, whereby more mercury is pushed into the stem, and its effect is especially observable in thermometers which have been graduated soon after being filled. If the error from this cause is not more

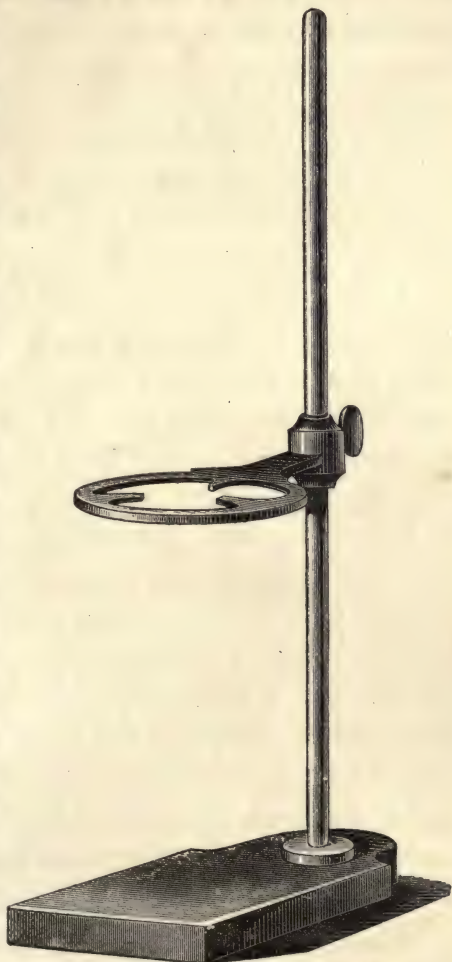


FIG. 383 (*an. proj.*; $\frac{1}{4}$ real size).

than 0.5 or 1° , and if the displacement affects both the freezing and boiling point by nearly the same amount, the thermometer may still be used, provided that the error is noted, and at each reading applied as a correction.

When a body expands we may consider solely the increase of one of the linear dimensions of the body; this is called the *linear expansion* of the substance of which the body consists, and the elongation of the unit of length of a body, when its temperature rises from 0° to 1° , is called *the coefficient of linear expansion* of the substance. Similarly we may consider the increase in area of any portion of its surface; this is called the *superficial expansion*, and the increase of the unit of surface in being heated from 0° to 1° is called the *coefficient of superficial expansion*. Finally, the increase in volume is called the *cubical expansion*, and the increase of the unit of volume when the body is heated from 0° to 1° is the *coefficient of cubical expansion*.

The determination of the coefficients of expansion of substances requires complicated contrivances and laborious experiments, for a description of which the student must consult larger works. Table II., at the end of this book, gives the coefficients of linear expansion for a variety of the more important substances as they have been determined by such experiments.

If the coefficient of linear expansion of a body is known its cubical expansion can be easily calculated. Thus, according to Table II., the coefficient of linear expansion of zinc is 0.0000294 ; a cube of zinc, of which each edge is just 1^{cm} long at 0° , so that its volume at zero is 1^{cc} , will, when heated to 1°C. , increase each of its dimensions by $0^{\text{cm}}.0000294$, and its volume will thus be-

come $1.0000294 \times 1.0000294 \times 1.0000294 = 1^{00}.0000882$. The volume has thus increased by 0.0000882, and this number is therefore the coefficient of cubical expansion of zinc. But 0.0000882 is equal to 3×0.0000294 ; and if a like calculation is made for other substances, it appears that the coefficient of cubical expansion of a substance is just three times as great as that of its linear expansion. Similarly the coefficient of superficial expansion of a substance is twice as great as its coefficient of linear expansion.

Solid bodies which are heated do not increase their volume to any considerable extent, at least not within the ordinary ranges of temperature; but the force exerted in expanding is very great—for it is equal to the external force required to compress the expanded body to its original volume without altering its temperature—and the expansion is therefore in many cases of great practical importance.

An iron rail may be exposed in the winter to a temperature of -30° , and in the summer to one of 50° . If the length of the rail be 6^m at 0° , it will become shorter in the winter by $30 \times 0.0000123 \times 6^m$; this is equal to $0^m.002214 = 2^{mm}.214$; in the summer it will lengthen by $50 \times 0.0000123 \times 6^m = 0^m.00369 = 3^{mm}.69$. The total variation in its length may thus possibly amount to $5^{mm}.904$; and in laying down a line of railway this change of length must be taken into account, and space must be left between the rails to allow of their expansion; if they were laid down in the winter, end to end, they would expand in the summer, and then either become bent or forced altogether out of position.

Iron telegraph-wires hang in the summer more

loosely than in the winter. As such wires possess a comparatively great tension, the small elongation caused by being exposed to a higher temperature is sufficient to produce a very sensible depression of the middle of the wire.

Advantage is frequently taken in the mechanical arts of the contraction of hot metals during cooling. The walls of buildings, when leaning or bulging out, may be brought into position by the alternate heating and cooling of iron bars, which are firmly clamped on the outside, and pass through the building. The hoop of iron by which a carriage-wheel is surrounded is first heated and then put on the wheel; the whole being thrown into water, the iron hoop contracts with great force, and thus binds the spokes and rim firmly together.

The same principle explains many familiar facts. Thus, when a glass vessel is rapidly heated or cooled it often breaks. This arises from the *unequal* expansion of the glass. If the temperature of a piece of glass changes slowly, so that all parts expand or contract uniformly, the mutual relation and cohesion of the particles is not disturbed; but if the change is rapid, as, for instance, when hot water is suddenly poured into the vessel, then the portion of the surface in contact with the hot liquid expands much more rapidly than the portion underneath, and the expanding particles force those beneath them asunder; thus rupture takes place, which spreads, in consequence of the brittleness of the substance, until the crack extends right through the thickness of the glass from one side to the

other. When cold water is poured into a hot glass vessel the rapidly cooled superficial portion contracts more than that beneath the surface; hence the former cracks. Glass vessels with thick sides are more apt to crack than those with very thin sides; in the former case it takes much longer before heat passes to or away from the inner portion than in the case of vessels with thin sides, and these are besides more yielding than thick vessels, and therefore less liable to break if both kinds undergo like changes of form.

Utensils of glass, especially those with thick sides, after being formed from the molten material, require to be cooled very slowly, otherwise they become extremely brittle and comparatively useless. The reason of this is not yet quite exactly known, but it is probable that during rapid cooling sufficient time is not given to the particles to assume that uniform aggregation which is a condition of their stable position; some neighbouring molecules may possibly be farther apart from each other than others, and hence a state of great constraint may exist among the molecules, so that a comparatively slight external impulse causes a sudden disruption of the whole.

Prince Rupert's Drops (or 'Dutch tears') and *Bolognian Flasks* are interesting examples of these facts. The former (fig. 384 A) are large drops of fused glass which have been let fall into a vessel of cold water. Many of these drops break to pieces immediately when they touch the water, but those which remain entire exhibit considerable strength. When placed upon a piece of wood they will bear pretty smart blows with a

hammer without breaking. It requires rather considerable force to break a piece 1^{cm} long off the tail; frequently it cannot be done with the fingers, but the flat

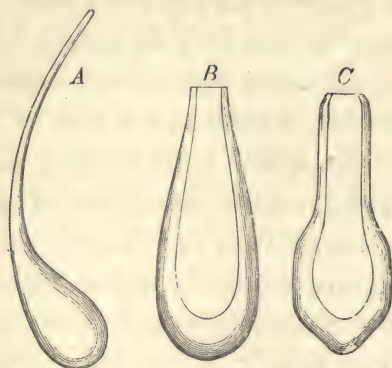


FIG. 384 (*A*, real size; *B*, *C*, $\frac{2}{3}$ real size).

pliers must be used. No sooner, however, is the extremity of the tail broken off, when in an instant the entire mass cracks and is reduced to innumerable extremely small pieces of glass, like grains of salt, and even partly to a fine powder.

'Bolognian flasks' are simply small glass bottles, which, after being formed, have been suddenly cooled in the air; they have usually one of the forms shown at *B* and *C*, fig. 384. The flask is sufficiently strong to bear a smart blow upon the outside; for example, it may be held within the closed hand, and the thick end, which is allowed to project, may be struck with considerable force against a wooden table, or it may be let fall upon a stone from a height of one metre. It will not usually break in these cases, or at most a small splinter of glass will be broken off the convex larger portions of the flask. But when a bit of glass or flint, measuring about 6^{mm} or 8^{mm} each way, with sharp angles,

is dropped into it, or the flask is slightly shaken while the piece of flint is in it, it falls to pieces.

The thick end of a Prince Rupert's drop may be held in the left hand while the tail is broken with the forefinger and thumb of the right hand; a small explosion takes place, and a slight blow is felt in the left hand. There is no real danger in making the experiment, which may be rendered still more safe by making a small hole in a piece of writing-paper, pushing the tail partly through the hole, wrapping the paper round the thick portion, and holding the covered drop in the left hand while the point is broken off. The small fragments have obtuse edges, but if a Bolognian flask is shivered the fragments are rather sharp, and care must be taken when they are removed.

When the stopper of a bottle or decanter becomes firmly fixed, it may often, but not always, be loosened by moderate continued knocks applied with a piece of wood sideways against the handle of the stopper. If it cannot be moved by this means the neck is heated over a spirit or gas flame, the bottle being constantly turned, and the neck heated not more than the hand can bear. Since the neck becomes hot before the stopper, it expands first, and the stopper is freed from its hold. After the stopper has been removed it must not be put into the neck again until the latter has become quite cold; otherwise the stopper sinks deeper into the expanded neck, and when contraction takes place the neck either cracks or closes so firmly around the stopper that its removal afterwards can scarcely be accomplished by heating it again.

It has been already shown that liquids, when heated, expand more than solid bodies. This fact may be further demonstrated by means of a small 'float' of glass, (fig. 385), partly filled with water, and so adjusted that it floats in cold water and projects a few millimetres above the surface of the liquid. When placed in boiling or at any rate very hot water it sinks to the bottom of the liquid. Since the volume of a body which is heated increases, while its absolute weight remains unaltered, the specific gravity of a body must clearly decrease when it is heated, and become the less the more the body expands.

Now, in this case the specific gravity of the cold water is greater than that of the float, while when the water is hot its specific gravity is less than that of the float; but since both bodies shortly after the float is immersed

are at the same temperature, we see that the decrease in the specific gravity of the water is greater than that in the float, and that consequently within the same range of temperature the expansion of the water has been greater than that of the float.



The float is made of a small test-tube, which is drawn out to a point over a spirit or gas flame. The tube may be much better handled during the operation, and it may be drawn out very near the mouth without burning the fingers, if a moderately tight-fitting cork is pushed a few millimetres into the tube, so as to serve as a handle for turning the tube while it is heated. A small ($\frac{1}{2}$ real size). groove must be formed lengthways in the cork by two slanting cuts with a sharp knife, so as to allow the air to expand when the tube is heated; otherwise the confined air would blow out the glass into a bulb as soon as it became soft by the heat.

A small flame should be used for the heating, and the tube turned at a very uniform rate, without pulling the glass; for the part which is softened by the heat becomes narrower while the walls at the same time become thicker: if the glass were drawn out at once without allowing it to thicken, it would become much too thin and brittle. After the glass is drawn out to the desired width and has become cool a fine cut is made with a very sharp file, which is somewhat moistened, and the float is then broken off. It is filled with water, by means of a glass tube drawn out to a long narrow point, so that it sinks in cold water to within about 5mm or 6mm from the top. If too much water has been put in it is simply shaken out by holding the float with the aperture downwards. When the quantity of water is properly adjusted the tube is closed by holding it vertically, and directing the end of the blowpipe flame upon the extreme point of the glass, which must be quite dry; any water left within the aperture may be sucked out by means of the long narrow glass tube.

When heat is applied to the lower part of a vessel containing any liquid a series of ascending and descending currents are produced in the liquid, in consequence of the difference between the specific gravity of the hotter portions of the liquid and that of the colder. The portion nearest to the source of heat becomes heated first, this makes it lighter, and it ascends, while its place is supplied by colder and heavier liquid, which descends, becomes heated in its turn, and ascends in like manner. These ascending and descending currents cause a circulation of the liquid, which goes on until the whole mass has the same temperature, as may be observed very easily by means of a test-tube filled with water and held in the edge of a flame, as in fig. 386. The current of heated water ascends on the upper side of the tube and the current of cold liquid descends on the lower side.

FIG. 386 ($\frac{1}{3}$ real size).

Water, unless specially purified, contains nearly always a sufficient number of floating particles to show the circulatory movement, when the water is heated. Or a minute bit of blotting-paper, about 1^{mm} in size, should be rubbed down in a mortar with a few drops of water; the fibrous shreds, when thrown into a test-tube filled with water, will show the circulation very distinctly.

If two communicating tubes contain the same liquid, and the liquid in one tube has a higher temperature than that in the other, the surface of the liquid will have a somewhat higher level in the warm tube than in the colder one. The difference of level is most easily seen if

the liquid used is paraffine oil. Fig. 387 shows a contrivance which permits the heating of the paraffine oil without danger. One branch of the bent tube is fixed



by means of a perforated cork so as to be within a wider tube ; the narrower tube is first filled to within a few centimetres from the top with paraffine oil, and then the wider tube is filled up to the mouth with hot water.

The small funnel-shaped piece of glass broken off in preparing the float (fig. 385) may be used for filling the narrow tube with paraffine oil ; the use of a pipette for the purpose is not advisable, as it is difficult to clean it afterwards completely. A lamp cylinder, with its wider opening upwards, may be used for holding the hot water, if a straight glass tube of the requisite width is not at hand. Such a cylinder is very liable to crack when hot water is poured into it, but this may be prevented by placing it in a large pan with cold water, heating the water until it boils, and then allowing the water to cool very slowly.

FIG. 387
($\frac{1}{4}$ real size).

As has been stated previously, mercury is the only liquid which has been found to expand at a nearly uniform rate. Water when it is near the freezing-point shows a peculiar and anomalous behaviour in this respect. Water at 0° does not expand when heated, but its volume becomes slightly smaller until its temperature is 4° ; from this point, when the heating is continued, it expands again, and its rate of expansion becomes greater and greater as its temperature rises. It follows that a mass of water occupies the smallest possible volume at 4° , and that its specific gravity is greatest at that temperature, or, as it is usually expressed, *water has its maximum density at 4° .*

The specific gravity of water at 4° is that taken as a

standard of comparison for other bodies—that is, it is assumed as $= 1$,—and the number which expresses exactly the specific gravity of any other body indicates how many times heavier that body is than an equal volume of water at the temperature of 4° . The *gramme* is the weight of one cubic centimetre of water at 4° .

The temperature of the body which is compared with water is taken as 0° , unless stated otherwise. For example, when the specific gravity of mercury is said to be $13\cdot596$, this means that any quantity of mercury is $13\cdot596$ times as heavy as a volume of water at 4° , equal to the volume which the mercury occupies at 0° . When no great exactness is required the specific gravity of water may also be assumed as $= 1$ at temperatures which do not considerably differ from 4° , or rather the small error in such cases may be neglected. The exact specific gravity of water is, however, at 0° , $0\cdot99988$; at 10° , $0\cdot99975$; at 20° , $0\cdot99831$; but at 100° it is sensibly less, viz. $0\cdot9588$.

The determination of the coefficient of expansion of liquids is a somewhat laborious operation, because liquids must be contained in vessels of some kind, and changes of temperature affect not only the liquid but at the same time also the vessel. The change of volume which water undergoes near its freezing-point is especially difficult to determine with accuracy, because the magnitudes to be measured are exceedingly small; thus, the expansion

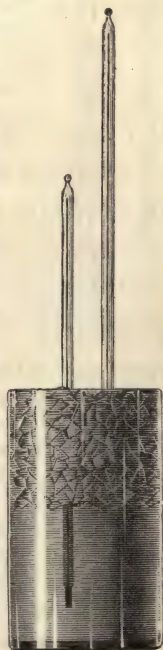


FIG. 388 ($\frac{1}{8}$ real size).

of water between 4° and 0° amounts only to $\frac{1}{8000}$ th of its volume.

That water at 0° is lighter than water at 4° may be easily demonstrated. Into a rather large glass of water a quantity of pounded ice is thrown sufficient to fill nearly the upper half of the glass, and two thermometers are inserted into it, as shown in fig. 388, one bulb being in the middle of the ice, the other reaching to near the bottom of the vessel.

The particles of water in contact with the ice are cooled and sink down to the bottom of the vessel; the descent will last as long as the effect of the cooling is to make some of the water heavier than the remainder; that is until the temperature of the descending particles has fallen to 4° . As the cooling proceeds the particles become lighter, and remain on the top; consequently after the vessel has been left undisturbed for some time the lower thermometer indicates nearly 4° and the upper about 0° . The reason that the thermometers do not exactly remain constant at 4° and 0° respectively is, that the air surrounding the vessel continually gives up heat to the vessel and indirectly to the water.

The experiment should be made in a cool room, as the warm air around the vessel affects the temperature of the liquid very considerably, and will cause so lively a circulation of particles within the body of the liquid that the portions which differ in density are scarcely ever distinctly separated. If the temperature of the room is maintained at 2° the two thermometers will indicate exactly 0° or 4° respectively. Both thermometers must be supported in the desired position by retort clamps.

In the case of liquids we obviously cannot speak of

a coefficient of linear expansion, but only of their coefficient of cubical expansion. The coefficient of cubical expansion increases for most liquids very rapidly with the temperature; only for mercury it is approximately uniform within a considerable range of temperature; between 0° and 100° it is $=0.00018153$, or $\frac{1}{5509}$. This is the coefficient of *absolute* expansion; that is, that which would be observed if the vessel in which the mercury is contained did not expand at the same time. The coefficient of *apparent* expansion of mercury contained in a *glass* vessel—in other words, that which is in this case actually observed—is less, and amounts only to $\frac{1}{6480}$; for the coefficient of absolute expansion of a liquid is very nearly equal to the coefficient of apparent expansion of the liquid together with the coefficient of cubical expansion of the substance of the vessel in which the liquid is contained.

The change in the specific gravity of mercury caused by changes of temperature must be taken into account when the pressure of the atmosphere is to be accurately determined by the barometer. In order to make the indications of this instrument comparable in different places and at different times they are ‘reduced to 0° ’; that is, the height of a column of mercury at 0° is calculated, which would exert the same pressure as that which is indicated by the barometer at the temperature at which the observation is actually made. This ‘correction of the barometric height’ may be made according to the following rule: Multiply the height of the barometer by 5509, and divide the product by the sum of 5509 and the number of degrees indicated by the thermometer; the quotient is then the corrected

height. Suppose, for example, that the barometer reads 755^{mm} when the temperature is 16°; then the corrected height is $\frac{755 \times 5509}{5509 + 16} = \frac{4159295}{5225} = 752^{\text{mm}}.8$.

Gases are not only more expansible than solids and liquids, but their expansion is also quite regular; moreover, while the expansion of solids and liquids is different for each different substance, the coefficient of expansion is the same for all permanent gases, viz. 0.003665, or $\frac{1}{273}$. This must not be understood to imply that a quantity of gas at any temperature will expand by $\frac{1}{273}$ of its volume when its temperature rises by 1°; it means that the gas under consideration will expand for a rise of temperature of 1° by $\frac{1}{273}$ of *that volume which it would occupy at 0°*. Thus 273° of air at 0° expand for each degree by which the temperature is raised $\frac{1}{273}$ of 273°; that is, 1°, and the volume therefore becomes 274° at 1°. At 100° it becomes 373°, at 101° it is 374°; it follows that when air at 100° is heated 1° it expands $\frac{1}{273}$ of the volume it had at 0°, and $\frac{1}{373}$ of the volume it occupies at 100°.

When air or any other gas is heated in a closed vessel, so as not to be allowed to expand more than the vessel itself (an expansion which is in all cases very small in comparison), it presses against the sides of the vessel with a force proportional to the expansion which would have taken place if the enclosed gas had freely expanded, the pressure of the atmosphere remaining the same throughout; in other words, the pressure on the sides of the vessel is the same as if the gas, after being allowed to expand freely while the external pressure remained constant, were afterwards compressed

into its original bulk. If 1° of air be heated from 0° to 100° , the pressure remaining constant at 760^{mm} and the air therefore being allowed to expand, it expands by $\frac{100}{273}$, and the volume at 100° becomes $1\frac{100}{273}$. But if $1\frac{100}{273}$ of air be compressed into the bulk of 1° the pressure of the gas, according to Mariotte's law, increases in the proportion of 1 to $1\frac{100}{273}$, and its actual amount may be found by the proportion

$$1 : 1\frac{100}{273} :: 760^{\text{mm}} : x$$

$$x = 760 \times \frac{373}{273} = 1038^{\text{mm}} \cdot 4.$$

The specific gravity of gases varies considerably with the temperature, in consequence of their rate of expansion, and the influence of these changes cannot be disregarded as it often may be in the case of solids and liquids; for even within the ordinary range of natural changes of temperature the specific gravity of gases may vary as much as several tenths of the amount; and it is also obvious from what has been stated that the pressure under which a gas has been experimented upon when its specific gravity was determined must be distinctly stated when the result of the experiment is given. In Table I. (at the end of this volume) the specific gravity of some of the most important gaseous bodies is given, the temperature being 0° , and the pressure that of a column of mercury 760^{mm} high.

The following calculation is an example of the application of the preceding principles. A litre (1000°) of air, at 0° and 760^{mm} pressure, weighs $1 \cdot 293$ gramme.

When heated to 15° it expands $1000 \times \frac{15}{273} = 54^{\circ} \cdot 945$, and the volume becomes $1054^{\circ} \cdot 945$. A quantity of

water of the same bulk weighs $1054^{\circ}\text{C} \cdot 945$ grammes, and the specific gravity of air referred to water is consequently $\frac{1.203}{1054.945} = 0.001226$. Let now the tempera-

ture remain constant and the pressure become 744^{mm} ; the bulk of the gas would then by Mariotte's law increase in the proportion of 744 to 760; that is

$$744 : 760 :: 1054.945 : x$$

$$x = 1077^{\circ}\text{C} \cdot 62.$$

The volume of 1.293 gramme of air at 15° and 740^{mm} pressure is thus $1077^{\circ}\text{C} \cdot 62$; and as the weight of an equal volume of water is 1077.62 grammes, it follows that the specific gravity of air under those conditions of temperature and pressure is $\frac{1.293}{1077.62} = 0.0012$. The

specific gravity of any gas at any temperature and pressure may be similarly calculated, if its specific gravity at 0° and 760^{mm} pressure is known.

Since gases expand more than liquids and their specific gravity diminishes much more rapidly when they are heated, the upward and downward movements of the particles of a heated gas proceed at a much quicker rate than in liquids. In the contrivance (fig. 200) represented on page 302, the ascent of heated air is taken advantage of for giving motion to a spiral of paper. In a room where a fire is kindled a current of warm air begins to ascend immediately; and if the hot air be cooled by contact with the walls and windows, a complete circulation of the air will be maintained in the room, the hot air constantly ascend-

ing from the vicinity of the fire, flowing along the ceiling to the walls and windows, becoming colder and descending, and finally flowing along the floor towards the fire to complete the circle and to ascend again. The draught in the chimneys of fireplaces and lamps is also a consequence of the fact of hot air being lighter than cold air.

The circulation of air in a room may be demonstrated by sprinkling a few drops of perfume upon the floor very near to the fireplace. Of several persons in the room, those near the window will perceive the odour first, those in the middle of the room next, and those near the fireplace last. The experiment will not succeed completely unless all draught from windows or side-doors is carefully excluded.

When the air in each of two adjoining rooms has a different temperature, and communication is allowed between them, the colder and heavier air flows below, along the floor, from the colder room into the warmer, while the warmer and lighter air flows above, near the ceiling, from the hotter room into the colder. By a similar circulation the whole atmosphere of the earth is kept in continual motion. *Winds* are caused by currents of air resulting from a difference in temperature between adjacent regions of the earth. Thus if the temperature of a certain extent of country rises, the air in contact with it becomes heated, it expands and ascends towards the higher regions of the atmosphere, while, in consequence of the difference in the specific gravity of the hot and the neighbouring cold air, a current of cold air will be produced in an opposite direction; that is, two distinct winds will be produced, an upper one setting *from* the heated region, and a lower one setting *towards* it.

On a small scale this opposite flow of air may be demonstrated by opening a few centimetres a door which leads from a warm room into a cooler room or a passage, and holding a lighted candle in the opening. The flame when held above, near the top of the door, is blown *from* the room; when placed below, near the floor, it is blown *into* it; when held midway between top and bottom it is blown neither way and burns pretty steadily.

✓ 55. *Melting and Freezing.*—Heat diminishes the cohesion between the particles of a body, and increases their expansive force. This is proved by the increase in volume and the diminution of rigidity in solids which are heated; for example, red-hot iron is much softer than cold iron.

In solids the cohesion exceeds by far the expansive force of the molecules (see page 18); but if by heating a solid the cohesion is more and more diminished, while the expansive force is continually increased, a point will be reached when the cohesion exceeds the expansive force only by a small amount, so that at a certain point of temperature the solid body becomes liquid; it is then said to ‘melt.’ On the contrary, if a liquid, by being cooled, becomes solid, it ‘freezes’ or ‘solidifies.’ The temperatures at which solids melt or liquids solidify, are very different for different substances, but each substance melts at a fixed temperature, which is the same as that at which the same substance in the liquid state freezes. These temperatures are, respectively, called the ‘melting point’ or ‘point of liquefaction,’ and the ‘freezing point’ or ‘point of solidification’ of the substance. For example, the melting point of ice is 0° , and this is also the freezing point of water. When ice which is colder than 0° is brought into a warm room, its temperature rises to 0° (see page

765), and it remains stationary at that point until the ice is completely melted. If a vessel containing water is placed in a cold space, or, in warm weather is cooled by means of a freezing mixture (see page 831), its temperature sinks to 0° and remains constant at that point until it is completely frozen.

The following small table contains the melting points of a few substances ; up to that of lead they may be determined with a common thermometer, but those that are higher can only be found by difficult experiments, which cannot be described here.

Table of Melting Points.

Wrought iron .	1500 to 1600°	Lead . . .	330°
Steel . . .	1300 to 1400°	Cadmium . . .	321°
Gold	1200°	Bismuth . . .	256°
Cast Iron . .	1050 to 1200°	Tin	230°
Copper	1050°	Sulphur . . .	111°
Silver	1000°	White wax . .	65°
Zinc	360°	Mercury . . .	-39°

A solid body cannot be heated beyond its melting point—for example, ice cannot be heated beyond 0° —without undergoing liquefaction. But the converse does not hold strictly in the case of liquids, for under particular circumstances liquids may be cooled below their freezing point, that is, below the melting point of the corresponding solid body, without solidifying. This exceptional phenomenon of the ‘retardation of solidification,’ can only take place if the liquid is cooled very slowly and is at the same time protected from all mechanical disturbance. On a severe frosty morning in the winter a glass of water may be found liquid in a room of which the temperature has slowly fallen during the

night to several degrees below 0° ; but the least agitation, as in attempting to pour the water out, converts the whole instantly into a mass of ice crystals.

This retardation of solidification is also observable in water deprived as much as possible of the air which it ordinarily holds in solution; hence water kept perfectly at rest in the vacuum of a receiver will not freeze unless cooled several degrees below 0° . A glass vessel which is partly filled with water, while the remaining space is free from air, a so-called 'water-hammer' (see art. 56), is especially suitable for showing the pheno-

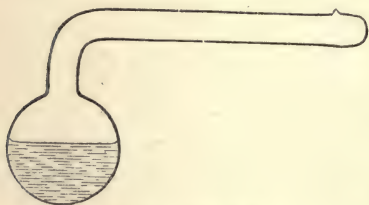


FIG. 389 ($\frac{1}{4}$ real size).

menon of continued liquidity. One form of the water-hammer, which is very serviceable for a variety of experiments, is represented in fig. 389.

If a water-hammer of this kind be placed on a moderately cold winter's day in the open air, we may be pretty sure that the water will not freeze as long as the instrument is kept at rest, even if the temperature should fall to 10 or 15° below the freezing point of water; but as soon as it is agitated, the water will immediately congeal.

The experiment with the water-hammer may be made in a room and in a comparatively short time, by placing it in a freezing mixture (see art. 58) made of common salt and ice. If ice at 0° is mixed in a suitable proportion with salt, the temperature of the mixture falls to from -18 to -21° . This is too low a temperature for the experiment, and the water in the vessel simply freezes; but the experiment will mostly succeed if made in the following way. A basin or wide pot, of about 1 litre capacity, is filled with ice pounded into small fragments, and water is poured on to the ice until it is nearly covered with it; a good handful of salt is now sprinkled

over the ice, and the bulb of the water-hammer, which is clamped in the position shown in the figure, is immersed in the mixture. After 10 or 15 minutes the water is cooled below 0° , but is still liquid; the apparatus is then gently raised out of the mixture, and cautiously wiped with a cloth so as to avoid moving the vessel containing the water. It is then vigorously shaken, and the water will be converted into ice.

The crude rock salt of commerce is more economical for freezing mixtures than table salt.

In order to prove by means of a thermometer that the temperature of the water really falls below its freezing point, the instrument must be placed in the liquid before it is cooled. To insert the thermometer into the liquid after it has been cooled to a temperature lower than its point of solidification would be quite useless, for the immersion of the instrument causes an amount of agitation which is sufficient to produce solidification of the liquid, and this is always accompanied by a disengagement of heat and a rise of temperature of the whole liquid up to its ordinary freezing point, which would therefore be the temperature indicated by the instrument. The temperature to which the water is cooled may be observed, if a glass flask is nearly filled with water and then closed by a perforated cork, through which a thermometer passes. The bottle may then be placed during the winter in the open air, and as the liquidity is longer continued in a closed vessel than in one which is quite open, the phenomenon is likely to be completely observed on the first occurrence of frosty weather.

The retardation of solidification and the disengagement of heat at the moment when solidification takes place may be well observed in the case of sodium hyposulphite, a white crystalline salt largely used in photography. The salt melts at 57° , and when carefully cooled it remains liquid at the ordinary temperature of the atmosphere. It may then be made to solidify by a rapid agitation, or still better, by sprinkling over the surface of the liquid a few grains of the solid salt. The rise of temperature resulting from the solidification is such as to be distinctly felt by the hand.

About 100 or 200 grammes of sodium hyposulphite should be melted in a small glass flask in a hot-water bath; if heated over a flame the flask is very apt to break. It is best to place the flask in a small pot of water, so narrow that the flask cannot be upset, and to support the pot suitably over a spirit-flame, until the last grain of the solid salt is melted. If even the smallest quantity of solid salt remains in the liquid, it would prevent the retardation of solidification taking place. It will take some hours for the melted mass to cool to the temperature of the atmosphere.

Alloys, that is mixtures of metals formed by fusing and mixing together several metals, have mostly a lower melting point than would be expected by taking the average of the melting points of the metals of which they are composed; it even happens in many cases that the melting point of the alloy is lower than that of any of the component metals taken separately. Thus soft solder, an alloy of tin and lead, melts at 170° , or 60° below the melting point of tin. Most striking is the low melting point of 'Wood's fusible metal,' which is an alloy of 7 parts, by weight, bismuth, 4 parts lead, 2 parts tin, and 1 part cadmium. This alloy melts between 66 and 70° . It becomes liquid when placed in pretty hot water; or the end of a small bar of it may be melted over the flame and the liquid metal allowed to fall upon the fingers without burning them.

Bismuth is a very brittle metal of a reddish-white colour, and can be reduced to powder by pounding it in a mortar. Cadmium is a white soft metal, which has a great resemblance to zinc. For preparing Wood's metal the bismuth should be fused first, in an iron ladle, then the lead, tin, and cadmium should be added, stirring the whole with a splinter of wood. No more heat should be applied than is sufficient to fuse the whole, as otherwise too much of the metals combines chemically with oxygen, that is, it is burnt away. It is advisable to take not less than 14 grammes bismuth, 8 grammes lead, 4 grammes tin, and 2 grammes cadmium. For preparing a small bar, the alloy is melted in a test-tube of boiling water, the

water is then poured off, and the melted alloy allowed to flow into a little cylindrical mould made of paper, 5 or 6^{mm} in diameter. Wood's alloy is rather brittle when near its melting point; tin at about 200° shows the same behaviour. At ordinary temperatures the alloy is pretty hard and somewhat elastic.

The passage of a body from the solid into the liquid, or from the liquid into the solid state, is generally accompanied by a change of volume. The behaviour of different substances is very different in this respect. In many cases the alteration of volume is very slight, in others it is very considerable, and in some substances the nature of the change is of an opposite kind to that which is observable in other substances, in other words, some bodies contract at the moment of liquefaction, while in others the volume becomes increased while they are passing into the liquid state. Whether one or the other change is taking place may easily be decided by observing whether any portion of the substance which is still in the solid state, while liquefaction proceeds, *floats* in that portion which is already liquid, or *sinks* in it.

If a piece of stearine candle from which the wick has been removed, about 20 grammes in weight and broken up into several pieces, be heated in a capacious test-tube until a portion of the stearine is melted, the pieces which are still solid will be seen to remain at the bottom of the tube. Solid stearine is therefore heavier than liquid stearine—stearine expands during liquefaction.

On the other hand, ice floats upon water, as is well known. Ice is thus lighter than water; ice contracts during liquefaction. The specific gravity of ice, when perfectly free from air bubbles, is nearly $\frac{11}{12}$, or more

exactly 0.91674; 12° of ice weigh 11 grammes, and give 11° of water when melted. It follows that water which freezes increases its volume by $\frac{1}{11}$. This increase of volume in the formation of ice takes place with great force so as to produce powerful mechanical effects, of which, in winter, the bursting of water-pipes and the breaking of jugs containing water are familiar examples.

If a bottle filled with water and tightly corked be exposed to the cold on a frosty day, the cork is often lifted by the expanding water, but as the liquid in the neck soon freezes so as no longer to allow a further expansion in that direction, the flask soon bursts.

A closed glass vessel, prepared in the same manner as the little float, fig. 385, but filled up to the narrow neck with water, may be burst by placing it for a few minutes in a freezing mixture made of 600 grammes of pounded ice and 200 grammes of salt, adding no water, and preparing the mixture in a flat tin basin, as vessels of glass or china are liable to be broken by the explosion. The little glass vessel is generally split into numerous long splinters, but sometimes only the point is cracked off.

56. Evaporation, Ebullition, and Condensation of Vapour.—Moist bodies exposed to the air become gradually dry. The water which was in or upon them passes into the gaseous state and disappears by diffusing itself into the surrounding air; it is said to ‘evaporate.’ Other liquids behave in this respect like water. Some liquids, for instance mercury, evaporate extremely slowly; others, for example ether and disulphide of carbon, evaporate much more rapidly than water. In all liquids the rate at which evaporation proceeds becomes higher if the temperature rises.

At a particular temperature the formation of vapour takes place with greater rapidity than at lower temperatures, and large bubbles are disengaged from the liquid which produce a violent agitation throughout its mass.

The liquid is then said to 'boil,' and the formation of vapour while the liquid boils is usually denoted by the term 'ebullition.'

As in the case of solids the cohesion is diminished by heat, and at the same time the expansive force of the particles increased, so is the evaporation and ebullition in a liquid body caused by the fact that heat continues to diminish the cohesion and to increase the expansive force until the expansive force considerably exceeds the cohesion, and it will be seen further on that even at common temperatures liquids receive heat during the progress of ordinary evaporation.

Steam, the vapour of water, is, like most other gases, perfectly colourless and transparent and therefore invisible. This is easily proved by boiling some water in a glass retort or flask with a narrow neck; the space above the boiling water is after a little time filled with steam, but it appears perfectly clear and transparent. But as the steam issues from the vessel it becomes visible and at the same time ceases to be true steam, being converted into water, which in the form of small drops suspended in the air appears as fog. If a liquid which contains solid bodies in solution be evaporated, the solids are left behind, and since the vapour may by suitable means be condensed and the liquid collected, we have thus a means of separating liquids from impurities which arise from admixture of solids in solution. This process of evaporation and re-condensation of a liquid is called *distillation*. The apparatus in which the vapour is condensed, the 'condenser,' consists usually of a tube which is surrounded by a wider vessel filled with cold water; as this water soon becomes heated by

contact with the tube which contains the hot steam, provision must be made for a frequent renewal of the water in the condenser.

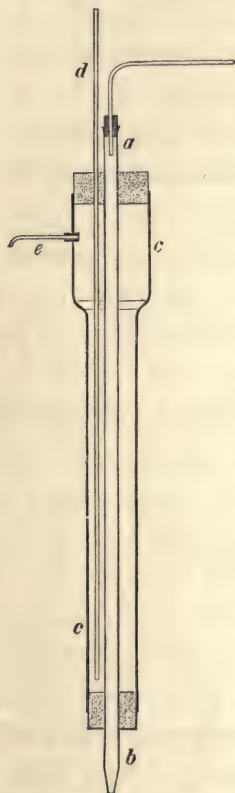


FIG. 390 ($\frac{1}{4}$ real size).

A simple apparatus of this kind is shown in fig. 390. A wide cylinder of glass, *cc*, is closed at both ends by corks. A tube *ab*, having a somewhat narrower opening below than that above, passes through both corks of the wider tube; its upper end *a* is closed airtight by a cork perforated for a narrow tube which leads to the vessel in which the steam is generated. The lower end is loosely placed into the neck of a vessel which serves for receiving the condensed liquid. Cold water passes into *cc* by means of the narrow tube *d*, which reaches nearly to the bottom of *cc*, while the heated water flows off at the top of *cc* through the narrow tube *e*, which is fixed in the side of it.

The upper cork serves only for keeping the tubes *cc* and *d* in a steady position, and need not fit very tight; but the lower cork must close the lower aperture perfectly watertight, or otherwise the impure water in the condenser will run between cork and sides into the receiver, mix with the distilled liquid in it, and render it impure again. The mode of inserting the tube *e* in the side of the cylinder is the same as that described on page 41, for the contrivance fig. 40.

The cylinder may be either clamped in the retort-stand, by the narrower portion, or placed into the funnel ring of a filter-stand, so that the shoulder of the wider portion may rest on the ring. The tube *d* may be attached by a piece of india-rubber tubing to

one end of a siphon which is set up at a suitable height above the apparatus for distilling; or it may be connected with the water-pipes in the house if they are available for the purpose, and the flow may be regulated by means of the water-tap. If a siphon is used the flow must be regulated by a pinchcock, which is placed upon the india-rubber tube. In regulating the flow it is only requisite that the lower portion of *cc* shall always contain cold water; it does not much matter if the water which flows off at *e* is pretty warm. The liquid to be distilled is contained in a retort or flask for boiling, and a glass-tube, bent once or twice at right angles and passing through a cork in the neck of the flask, serves for conveying the vapour into the tube *ab*. As the bore of *ab* should be rather narrow, the perforated cork would have rather thin sides; it is therefore best to fix the tube which leads into *ab* by means of a short piece of india-rubber tubing. If a retort with a narrow neck is used, a clean wide india-rubber tube may be simply slipped at one end over the mouth of the retort and at the other over the opening at *a*, thus establishing direct communication between the retort and the condenser. The end *b* must sit loosely in the mouth of the vessel in which the distilled liquid is received, so as to allow the escape of the air from it, which is swept into it by the steam from the retort or flask in which the liquid is boiled, and also to permit any steam to escape which may not have been condensed in its passage through the tube *ab*.

The boiling should not be too strong, or drops of the impure liquid might be carried over as a fine spray by the rapidly evolved steam.

That solid bodies remain behind in the distillation of a liquid may be shown by adding to the water to be distilled a trace of magenta and a little salt. The distilled water has no taste and is colourless. The magenta is generally deposited upon the sides of the boiling vessel, and may be removed by adding a few drops of hydrochloric acid, and shaking the flask or retort.

When about half of the liquid has passed over, the operation should be stopped, as the flask or retort is apt to crack when the quantity of liquid is considerably reduced.

Like every other gaseous substance, steam has a certain expansive force, in virtue of which it exerts pressure on the sides of the vessel in which it is contained. At the temperature of boiling water the pressure, or tension, of the generated steam is exactly equal

to the pressure of the atmosphere ; at a lower temperature the pressure of steam is less, at a higher temperature it is greater than that of the atmosphere. A liquid in an open vessel cannot be heated to a higher temperature than its boiling point, for any addition of heat after the liquid has reached its boiling point is employed in the formation of vapour. Any cause, however, which prevents the escape of steam makes the temperature rise. If, for instance, water be boiled in a *closed* vessel, the water may be heated to any temperature, if the vessel be strong enough. The higher the temperature rises the greater becomes the pressure of the vapour, and if the vessel is not strong enough to resist the increasing pressure it very soon bursts with a loud report.



FIG. 391
(real size).

It is not advisable to attempt an experiment on the pressure of steam in a closed vessel of larger dimensions than that shown in fig. 391. Little glass bulbs of this size, already filled with liquid, are sold at the dealers in scientific apparatus by the name 'candle bombs.' When stuck in a lighted candle against the flame, or hung by a wire into a gas-flame, they soon explode. With larger vessels most serious accidents may be caused by the explosion.

The pressure of vapour of water heated beyond 100° is used on a large scale for giving motion to steam-engines.

If a vessel containing water is heated, and there is only a small orifice in the vessel, then the escape of the steam is impeded, and the temperature of the water rises to above 100° . The tension of the steam is in that case higher than the atmospheric pressure, and the steam is ejected through the orifice with considerable

force. Such a jet of steam is especially well adapted for showing the phenomena of reaction and suction.

A reaction apparatus moved by steam may be had from the dealers under the name 'Hero's engine,' or 'Eolipyle.' It consists of a hollow spherical vessel, capable of rotating about an axis, and fitted with two tubular appendages bent at right angles and having narrow apertures, similar to those in fig. 144 (p. 201). By immersing one of the apertures in water, and sucking at the other, the vessel may be partly filled with water, which is then made to boil by the application of a lamp. Very soon two jets of vapour are forcibly discharged through the apertures, and on the principle of reaction the globular vessel is driven round in an opposite direction.

A retort or flask is filled two-thirds with water, and closed by a cork through which a glass tube passes. The end of the tube is attached by means of an india-rubber tube to the horizontal tube of the contrivance fig. 205 (p. 315). When the water is boiled over a spirit-lamp the steam which issues produces a very powerful suction, and dissipation of the liquid spray.

The phenomena of suction may be rendered much more striking by using the little contrivance represented in fig. 392, the principle of which is applied on a large scale in the so-called 'injector,' which is a steam-jet pump for feeding the boilers of steam-engines. The steam issues from the small aperture of the tube *b*, the end of which reaches to within the narrow portion of the tube *c*; this part being, however, somewhat wider than the point of the tube *b*, so that the issuing steam may expand and its density diminish. Through *c* the steam passes out into the air, and at the same time also some air from the space within the wider tube *aa*, for as the density of the steam which issues from *b* is diminished, air rushes from the space *aa* into the narrow part of *c*, and is carried outwards by the steam. The air within *aa* becomes thus rarefied, and if the tube *d* dips in water, the pressure of the

atmosphere forces some water into the space *aa*. Gradually more and more air is ejected from *aa*, until the space becomes filled with water; then water alone is forced out by the steam, but the suction now be-

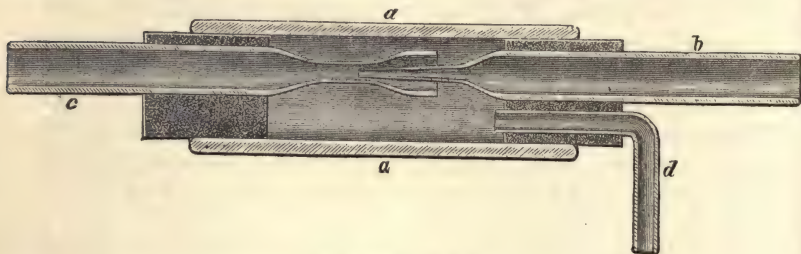


FIG. 392 (*real size*).

comes much more effective because the steam in contact with the cold water is immediately condensed to water; it occupies in that state much less space, and an almost complete vacuum is produced at the mouth of *b*; the water in consequence rushes with great force into the narrow part of *c*, and by its inertia continues its motion, so as to issue at the other end of *c*. When this happens a short piece of glass-tubing, bent upwards at right angles and drawn into a fine point, may be attached by an india-rubber tube to *c*, and the water made to issue upwards in a powerful jet.

The construction of the little injector presents no difficulty, but the dimensions of the various parts must be exactly those shown in the figure, if the action is to be depended upon. Each side of the right angle into which the jet tube is to be bent should be about 3^{cm} long, and the tube as wide as *c*; the pointed end should be like that of *b* or very little narrower. An india-rubber suction tube, 10 or 15^{cm} long, may be attached to *d*. The india-rubber tube employed for connecting the apparatus with the vessel in which the steam is generated should fit very tight; it must not be tied with thread, so that in case the pressure of the steam becomes

too great the india-rubber tube may be forced off the glass tube, instead of its being torn or the glass broken by the pressure.

The tension of steam is measured by the height of a column of mercury which it is capable of supporting.

The height of this column is :

	Millimetres.		Millimetres.
at 0° . . .	4·6	at 80° . . .	354·6
„ 10° . . .	9·2	„ 90° . . .	525·4
„ 20° . . .	17·4	„ 100° . . .	760·0
„ 30° . . .	31·5	„ 110° . . .	1075·0
„ 40° . . .	54·9	„ 120° . . .	1491·0
„ 50° . . .	92·0	„ 130° . . .	2030·0
„ 60° . . .	148·8	„ 140° . . .	2718·0
„ 70° . . .	233·1	„ 150° . . .	3581·0

For temperatures above 100° the tension of steam is often stated in numbers which express by how many times the tension is greater than the normal pressure of the atmosphere, which is taken as 760^{mm}; this normal pressure is thus the unit of comparison, and is usually simply called ‘one atmosphere.’ Compared with this unit the tension of steam is

at 100 degrees	1 atmosphere
„ 120·6 „	2 atmospheres
„ 133·9 „	3 „
„ 144·0 „	4 „
„ 152·2 „	5 „
„ 159·6 „	6 „
„ 165·4 „	7 „
„ 170·8 „	8 „
„ 175·8 „	9 „
„ 180·3 „	10 „

The tension of vapour at any temperature below 100° may be proved to be less than the pressure of the atmosphere by the following experiment. A retort, half filled with water, is closed by a cork perforated for the insertion of a glass tube 10^{cm} long and 5^{mm} wide.

The neck of the retort is slightly inclined downwards, and the end of the tube allowed to dip below the surface of water contained in a capacious basin or trough. Heat is applied until bubbles no longer escape from the tube, but the issuing steam is condensed with a hissing noise by the cold water in the basin. The flame is then removed, and as the temperature in the retort falls, the pressure of the external air forces the water up the tube, first slowly, but gradually more and more rapidly in consequence of the condensation of the steam inside the retort by contact with the cold water which enters. At last the water rushes in very fast and the retort becomes almost completely filled.

If the water in the basin and that in the retort have been boiled previous to making the experiment, so as to drive out the dissolved air, the retort will be filled completely.

The peculiar hissing sound which is heard when steam is condensed by being passed into water is caused by the clashing together of particles of water which are urged by atmospheric pressure to rush in from all sides to occupy the space left vacuous by the condensed steam. As water is very little compressible the sound is very similar to that produced by striking solid bodies together.

When steam is generated in a vessel only partly filled with water it will after a time expel the air from the space above the water, and if the steam is now condensed an almost perfect vacuum may be produced. If to the end of the tube which was immersed in water in the previous experiment, but is now taken out of it, an india-rubber tube be attached, and the water in the retort be boiled for a few minutes, all the

air in the retort will be expelled. The india-rubber tube may now be closed by a pinch-cock and the lamp immediately removed; the space within the retort no longer contains any air, but is filled with steam, of which the pressure is at first the same as that of the atmosphere, but as the temperature decreases the pressure also becomes less, and finally there will be in the retort only very rarefied steam exerting an inconsiderable pressure.

In the same manner the previously-mentioned water-hammer is exhausted of air. Where the small point appears near the end there was a short narrow tube through the opening of which the air has been driven out and which was then closed with the blow-pipe. When the apparatus is inverted so that some of the water strikes against

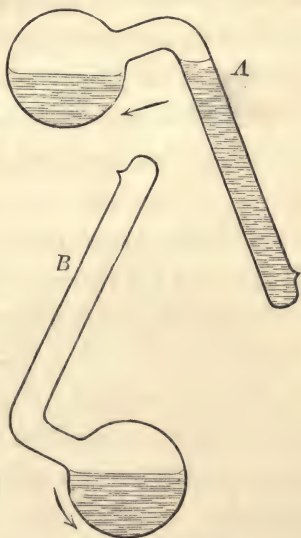


FIG. 393 ($\frac{1}{4}$ real size).

the extremity of the tube, or against another portion of the liquid contained in it, a sharp sound is produced similar to that which accompanies the condensation of steam in water. It resembles so much the shock of two solid bodies that, on hearing the sound for the first time, it appears as if the glass had been cracked. The sound is particularly sharp if the apparatus is either held in the position A, fig. 393, and moved quickly in the direction of the arrow, so that the water in the bulb strikes against that in the tube, or in position B, and

turned rapidly in the direction of the arrow so that the whole water falls from the bulb into the empty tube, and strikes against the glass.

It has been previously stated that at the temperature of the boiling point the tension of the vapour is equal to the pressure of the atmosphere upon the liquid. It would, however, be more correct to say, conversely, that *the boiling point of a liquid is that temperature at which the tension of its vapour is equal to the pressure it supports*. When the vapour has a lower tension, it is unable to displace the atmosphere, and can only diffuse itself through the air, but as soon as its tension becomes equal to the pressure of the atmosphere it is capable of lifting the air before it and of expanding freely.

Under diminished atmospheric pressure the tension

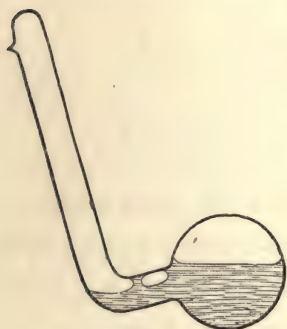


FIG. 394 ($\frac{1}{4}$ real size).

of the vapour need not be so high as to support a column of mercury of 760^{mm}, and the temperature is therefore less than 100° when the liquid boils. Hence ebullition may be produced at very low temperatures if the pressure be artificially diminished. To prove this a flask half filled with water at

40° or 50° may be placed under the receiver of the air-pump. When the air is exhausted the water begins to boil briskly. Or, without using an air-pump, water may be boiled in a retort until the air is expelled; the neck is then closed, and the retort immersed in a vessel with cold water. The rapid condensation of the steam in the retort produces a partial vacuum in it, and

in consequence of the diminished pressure the water in the retort soon begins to boil.

If the tube of the water-hammer be held between both hands in the position shown in fig. 394, the warmth of the hands will be sufficient to cause a rapid evaporation of the water which remains adhering to the glass. The vapour formed passes in bubbles through the water, but is soon condensed again in consequence of the low temperature of the water.

The following small table contains the boiling point of some substances at a pressure of 760^{mm}.—

Sulphur	448°	Alcohol	78°·4
Mercury	350°	Ether	34°·9
Sulphuric Acid	323	Sulphurous Acid . . .	— 10°·8

If alcohol or ether be used as the liquid in an apparatus similar to the water-hammer, ebullition is always much more brisk than in the water-hammer, because the vapour of alcohol and ether have a much higher tension than the vapour of water has at the same temperature.

When a small quantity of liquid is placed upon a surface which is considerably hotter than the temperature of the boiling point of the liquid, the evaporation presents remarkable phenomena. A small dish of copper or platinum is heated to redness, and a little water is dropped into it by means of a pipette or washing-bottle, as in fig. 395. Under these circumstances, the liquid does not spread itself out on the dish, it does not moisten it, and produces no hissing sound, as it would if placed upon a moderately hot surface, but it assumes the form of a flattened globule, like a drop of mercury. If the quantity of water is small, it re-

mains globular and nearly motionless; if the quantity is larger than 1^{cm} in diameter, it takes mostly the form of a star, and has a quick, tremulous, or sometimes rotatory, motion.

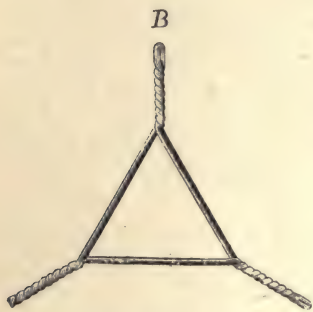
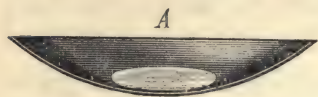


FIG. 395 (*A* real size, *B* $\frac{1}{2}$ real size).

The experiment is usually designated as 'Leidenfrost's experiment,' and the state in which the liquid appears under these circumstances has been called the *spheroidal state*. The hot support causes a rapid evaporation of the surface of the liquid drop as soon as it comes near the hot metal; the

vapour produced prevents actual contact with the hot surface, and a sort of cushion of its own vapour supports the liquid as long as the high temperature of the dish is maintained. The temperature of the liquid in the spheroidal state is always below its boiling point, and the evaporation does not proceed so quickly as might be expected from the high temperature of the metallic surface; but as the dish is allowed to cool, a point is reached in which it is not hot enough to keep the water in the spheroidal state; it is accordingly moistened by the liquid, and a violent ebullition ensues.

A copper dish is soon covered with oxide when made red hot, the inside must therefore be well polished with emery paper each time the experiment is to be repeated. Platinum does not become oxidised, but is rather expensive. The dish should be supported by a wire triangle, the form of which is seen from fig. 395 B, upon the ring of the boiling stand, and heated by a spirit-flame or a

gas burner. The water is not dropped in until the dish is quite red hot, and only drop by drop, and not in too large a quantity. The experiment is more easily made if the water used is made hot to begin with, as it is then not so liable to cool the dish below the temperature required for maintaining the spheroidal state. When the spheroidal state is sufficiently observed, the lamp is removed, and the water will soon be seen to boil very briskly.

When a liquid, especially one free from dissolved air, is slowly heated, a 'retardation of ebullition' may often be observed; that is, the liquid rises, without boiling, to a temperature which is higher than its boiling point. In an open vessel this retardation is not easily produced, nor is the experiment in that case free from danger, because when ebullition has been retarded and then at last does occur, it always takes place very suddenly and with great force, which is apt to shatter the vessel to pieces. The phenomenon may, however, be safely observed and conveniently produced by the water-hammer. The apparatus is first held in a horizontal position, the bulb upwards, and the end of the tube is repeatedly and very moderately knocked against the side of the table, a door-post, or any other fixed piece of wood. At first the sound at each knock is sharp, because the water is thrown back by the elastic glass wall, while at the same time a few bubbles are produced. But very soon the sound becomes dull, and is like that produced by knocking an empty glass against the wood. The apparatus is now ready for the experiment. It is then inclined until it assumes the position shown in fig. 396, taking special care that no bubble of vapour enters the tube, for if this happens the water in the tube sinks to the level of that in the bulb, as shown in fig. 397. If now the tube be warmed with both hands no vapour will be formed, and the tube may even be

heated over the lamp for some time without formation of vapour. Not until the tube is strongly heated, does ebullition commence ; but when it takes place, it causes

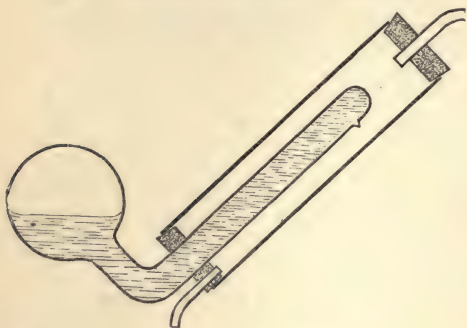


FIG. 396 ($\frac{1}{4}$ real size).

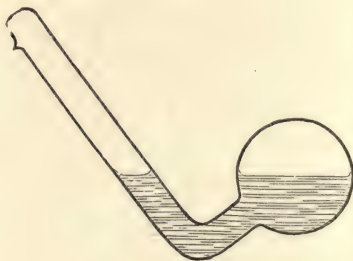


FIG. 397 ($\frac{1}{4}$ real size).

a violent agitation of the liquid, and the beginning of ebullition is distinctly felt by the hand.

Instead of using a lamp it is preferable to heat the tube by steam. The tube is fixed within a lamp cylinder by means of a cork, as shown in fig. 396. Steam is passed through a small tube fixed in the cylinder by a perforated cork, and connected by india-rubber tubing with a flask containing water. The small tube below allows the steam to escape. The whole contrivance is fixed by the bend of the water-hammer in the clamp of the retort-stand. The water in the flask is then made to boil, and ebullition in the water-hammer will not begin until the tube is considerably heated by the steam, while under ordinary circumstances the heat of the hand is sufficient to produce ebullition at the low pressure under which the water exists in the apparatus.

In the lower cork a small groove must be cut so as to allow the projecting point, near the extremity of the tube, to pass.

The pressure on the liquid within the water-hammer is so small that its boiling point is very low, and in this case the retardation of ebullition takes place at a low temperature. Similarly when the pressure is high, the retardation under favourable circumstances takes place at higher temperatures.

If the water-hammer is held in the position shown in fig. 397, and bulb and tube are alternately inclined downwards, the water will flow from one side to the other, so as to be always at the same level in both parts of the apparatus. The pressure of the steam which fills the spaces above the liquid must thus always be equal on both sides, whether the spaces or volume occupied by steam become larger or smaller, provided the temperature is on both sides the same. Vapours show this behaviour only when they are not mixed with air and when they are in contact with their liquid. In a vacuum a liquid forms vapour instantaneously, but for any given temperature there is a limit to the quantity of vapour which can be formed in a given space; when this limit is reached the space is said to be *saturated*. When the space is diminished a portion of vapour corresponding to the diminution of volume returns to the liquid state; when, on the other hand, the space is increased, a portion of the liquid present vaporises, and the space occupied by the vapour is again saturated.

If the space contains air, the same quantity of vapour may be formed in it as is formed in an equal space, free from air and at the same temperature, if a sufficient quantity of liquid be present; but the formation of vapour is not instantaneous, as it is in a vacuum; it proceeds much more slowly, and the saturation of an enclosed space containing air may require several hours.

The vapour in the water-hammer always saturates the space in which it is contained. Very different is the behaviour of vapour of which there is less in a given

space than the quantity required to saturate it at the actual temperature of the space, and which, therefore, has a smaller tension and density than it would have at the same temperature if the space were saturated. Such vapour is called *non-saturated*, or 'superheated,' because its temperature is higher than that required to maintain the same quantity as vapour, having exactly the same tension.

Non-saturated vapour exhibits the same kind of behaviour as a gas. Its tension increases in proportion to the pressure upon it; it decreases the more it is allowed to expand. It obeys in general Mariotte's law. Gases are supposed to be the non-saturated vapours of liquids which boil at temperatures more or less below the ordinary temperature of the air. For since non-saturated vapours have a smaller tension than the same quantity of vapour might have at the same temperature, it follows that those liquids, of which the non-saturated vapours are gases at ordinary temperatures, could at ordinary temperatures produce vapours of much higher tension than the pressure under which they exist, that is, the atmospheric pressure; consequently, these vapours must attain a tension of 760^{mm} at lower temperatures than the ordinary ones, that is, their liquids must boil at those lower temperatures.

By compressing non-saturated vapour more and more a point is finally reached when it saturates the space which contains it, and if the pressure exerted upon it is still further increased, it is reconverted into a liquid. The same effect may be produced by lowering the temperature sufficiently. Most gases may, indeed, be 'liquefied' either by lowering their temperature or by

applying considerable pressure, or by combining both means. Gases which have been actually liquefied are called 'coercible;' those which have hitherto resisted all attempts to liquefy them are called 'permanent' gases, but there is every reason to believe that these gases, of which oxygen, hydrogen, and nitrogen may be mentioned as instances, will be liquefied if the means of producing great pressure and a very low temperature which are at present at the disposal of physicists should be still further increased.

Ammonia, carbonic acid, and sulphurous acid are coercible gases. The liquefaction of sulphurous acid, which, as seen from the above table, has its boiling point at $-10^{\circ}.8$, is most easily effected. An adequate lowering of temperature is quite sufficient for the liquefaction of sulphurous acid; but in the case of ammonia or carbonic acid great pressure must be resorted to.

Experiments on the liquefaction of gases can only be undertaken by experienced hands and with the help of suitably constructed apparatus, because the tension of the vapours produced at ordinary temperatures by the liquids obtained is so enormous (for example, in carbonic acid it amounts to from 50 to 60 atmospheres), that most dangerous explosions may occur if the experiment is conducted by unskilled hands.

57. *Transmission of Heat. Radiation. Conduction.*—Heat may be transmitted from one body to another in two ways. One body may send out 'heat rays,' or thermal rays, in all directions and excite heat in another body at a distance without sensibly heating the intervening space, just as 'light rays' are given out by luminous bodies and pass through transparent substances. This mode of transmitting heat is called *radiation*. Or heat may be transmitted from one body to another by the

particles of the bodies themselves, and is then said to be transmitted by *conduction*.

Thermal rays have the same velocity as luminous rays, and are subject to the same laws of reflection and refraction. Certain *luminous* rays, viz., the red, orange, and yellow, are at the same time *thermal* rays; but many thermal rays do not produce upon our eye the impression of light, and are therefore dark. Such dark thermal rays are less refrangible than the red rays. A warm body which is not luminous emits only dark heat rays; luminous (that is, red, orange, and yellow) heat rays are only emitted by incandescent bodies, but even these emit at the same time considerably more dark than luminous heat rays.

The sun emits an immense amount of luminous and thermal rays, but much more of the heating effect of the sun is due to the dark than to the luminous thermal rays. Within the small image of the sun produced by a convex lens or a concave mirror, no more heat can be collected than that contained in a bundle of rays of the thickness of the diameter of the lens or mirror, and yet it is sufficient to ignite bodies which are easily combustible; while by means of larger appliances for collecting solar rays the most infusible substances have been melted, and some of the least combustible have been ignited.

Just as luminous rays are allowed to pass only through certain bodies, called transparent, and are stopped by other bodies, called opaque, so are thermal rays only transmitted through certain substances, which are called *diathermanous*, while all other substances which stop thermal rays are called *athermanous*. Many

substances which allow light to pass freely through them behave differently with regard to heat. Clear glass and water are transparent for light rays; but with regard to thermal rays glass is only diathermanous for such as are at the same time luminous, while it stops a portion of those which are dark. Water is only diathermanous for luminous heat rays. Rock-salt appears to be among solid bodies nearly the only substance which transmits freely all kinds of thermal rays. On the other hand, there are substances which are opaque to light but diathermanous for dark heat rays; for example, iodine dissolved in disulphide of carbon, and black glass.

Atmospheric air is in a high degree diathermanous. The solar rays pass freely through the atmosphere without warming it. If air, instead of being diathermanous, could stop heat rays, its temperature would be raised most where it first comes in contact with solar rays of yet undiminished thermal intensity, that is, at great elevations above the ground. But observations of the temperature of the air at various altitudes prove that the air is warmest near the surface of the earth, and that its temperature becomes gradually lower and lower as we reach greater altitudes. It follows that the air is not warmed by thermal rays which proceed directly from the sun, but by those which are emitted by the earth which has been heated by the solar rays.

Those substances which do not transmit heat rays 'absorb' a part and 'reflect' a part of the rays which impinge upon them. From the great analogy between radiant heat and light we may infer that smooth, bright, and polished bodies preferably reflect thermal rays, while dark and rough bodies preferably absorb them.

Polished metals are found accordingly to reflect the greatest part of the heat rays which impinge upon them, while the darkest of all known substances, lamp-black, absorbs heat rays as completely as luminous rays.

A piece of bright tinfoil upon which the sun's rays are brought to a focus by means of a lens, will be fused with difficulty or not at all ; but if the surface is blackened with lamp-black it will melt in the focus at once. The tinfoil purchased of the dealers is usually brighter on one side than on the other ; the bright surface should be used for the reflection of the rays, and the other surface should be blackened by holding it over a lighted splinter of wood which has been dipped in oil of turpentine or paraffine. To prevent the tinfoil being fused by the heat of the flame it should be rolled round a bottle filled with water or a rather thick cylinder of metal.

A small tin pan is blackened on one side by a turpentine or paraffine flame; some water is then made to boil in it and the vessel removed from the flame. If now the back of each hand be held about 1^{cm} from the sides of the pan, one hand opposite to the blackened side, and the other to the bright side, the hand opposite to the blackened side will feel the heat much more than the other hand. The blackened surface radiates much more heat than the bright surface. The same fact holds in the case of all other bodies. Substances which have the greatest absorbing power for heat have also the greatest radiating or emissive power. On the other hand, those substances which have the greatest reflecting power possess the least emissive power.

Whenever one part of a body is hotter than the remainder, heat flows from the hottest part to the neighbouring colder part, until this part has the same temperature as the first; from the second part heat flows to the neighbouring third part, and so on. There

is a flow of heat until the whole is at the same temperature throughout. In the same manner heat flows also from one body to another provided both are in contact with each other. This kind of transmission of heat is called *conduction*. Conduction takes place in different bodies with very different velocities; hence bodies are distinguished as 'good conductors' and 'bad conductors' of heat, a distinction which is very similar in principle to that made in the conduction of electricity, the more so as the best conductors of electricity are also the best conductors of heat, and *vice versâ*. The velocity with which heat is transmitted even by the best conductors is almost infinitely less than the velocity with which it is propagated by radiation.

Metals conduct heat with much greater facility than all other solids, but they differ among themselves very considerably in their conducting power. Two wires of the same length and thickness, viz., about 10^{cm} long and 1^{mm} or 2^{mm} thick, one of iron and the other of copper, are held at one end between the thumb and forefinger, one wire in each hand, and the other ends of the wires are placed in a flame. The copper wire soon becomes so hot that it cannot be longer held in the hand, while the iron wire may be held much longer. Copper is hence a better conductor than iron, for in the copper wire the heat flows with greater velocity from one end to the other than in the iron wire. If the iron wire is thin it can be held almost for any time; the reason is that at the outset a thin wire receives less heat than a thicker one, and so much of the received heat is lost by radiation and by contact with the air that the quantity which actually flows from one end to the other is very little,

and it takes therefore a considerable time before an appreciable effect is produced at some distance from the source of heat.

Among the metals silver and copper are the best conductors, lead is the worst. In general, all other inorganic substances are not so good conductors of heat as metals. Glass is a very bad conductor. The worst conductors of all solid bodies are porous bodies, derived from the animal or vegetable kingdom, such as wood, fibrous substances, feathers, furs, &c.

Bad conductors are used for preserving the temperature of bodies, that is, either to prevent abstraction of heat by colder bodies in their neighbourhood, or accession of heat from without if the body is at a lower temperature than those in its vicinity. Thus warm clothes, furs, &c, hinder our body from losing heat to the cold air by which it is surrounded in winter; houses with double walls, having between them badly conducting materials, such as straw, sawdust, ashes, &c., are used for keeping ice in the summer, for they prevent access of heat from the air without.

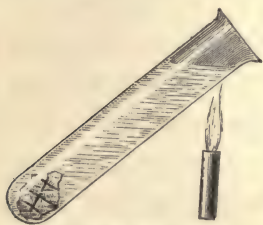


FIG. 398 ($\frac{1}{4}$ real size).

Liquids are bad conductors, with the single exception of the liquid metal mercury. It is only by convection, that is, by causing a circulation of their particles in the manner described on page 777, that the mass of a liquid can be heated throughout in a comparatively short time. When liquids are heated near the surface, the heated particles remain at the surface, while the heavier and colder particles continue at rest where they are; no circulation

takes place, and it can then be easily observed that it takes a very long time before the lower particles of the liquid become sensibly warmer. A test-tube is nearly filled with water, as in fig. 398, and some ice, weighted by a piece of wire wrapped round it, is placed in it. By inclining the tube, and heating the surface of the liquid by means of a spirit lamp, the liquid at the top may be made to boil, while the ice at the bottom remains unmelted. On the other hand, if the ice is placed on the top of the liquid, and the test-tube heated as in the experiment, fig. 386, applying only a very small flame, the ice will soon melt, because in this case the water heated at the bottom of the test-tube rises upwards and parts with its heat to the ice.

The most suitable wire for this experiment is lead wire; if this cannot be had, copper wire which has been softened in the flame should be wrapped round the ice. A very small flame should be used for heating the test-tube, and it should be held so that the point of the flame is a little below the surface of the liquid, not in a line with it, or the glass is sure to crack. The cracking of the tube may also be prevented by slightly shaking the water, so that the upper part of the tube may be uniformly and gradually heated; it must of course be done very gently, or the water will be agitated right through the mass, and the object of the experiment frustrated.

Air and all other gases without exception are bad conductors, and a flow of heat can only take place through them by an actual movement of their molecules, which must be produced by heating that portion of a gas which is lower than the remainder; the heated molecules thus become less dense, and rise, while the heavier portion gradually descends and becomes heated in turn. A space filled with air cannot be heated from above, for the heated molecules in the upper portion of the mass remain where they are, while those below

them remain at rest and become heated only very slowly. When the motion of gaseous molecules is restrained, they do not convey much heat, even if they are heated from the side or from below. The free motion of the air in a given space may be prevented by dividing the whole space, by numerous partitions, into smaller spaces. A free current is no longer possible under these circumstances, and such a space could no longer be effectually heated even by convection. It is in this way that substances like fur, feathers, ashes, fabrics, straw, &c., become bad conductors; the air remains stationary between their particles, and offers thus great resistance to the propagation of heat by preventing a free circulation of heated molecules.

58. *Specific and Latent Heat.*—Two bullets of equal size, one of zinc and the other of lead, each attached to a piece of iron wire which serves as a handle, are placed in boiling water and left in it until their temperature may be reckoned with certainty to be at 100° . They are then quickly taken out and placed on a cake of beeswax or tallow. The zinc will be seen to melt its way pretty deep into the cake while the lead penetrates but a small distance. Both metal balls are at the same temperature, and have the same size, and yet, although the leaden ball is more than half as heavy again as the zinc ball, the lead cannot melt as much wax, that is, does not part with as much heat as the zinc ball, whilst both are cooling from 100° to the temperature of the air.

Different bodies at the same temperature contain different quantities of heat; they part with different quantities when cooled through the same number of

degrees of temperature, and require different quantities of heat when their temperature is raised by the same amount. The quantity of heat necessary to raise the temperature of 1 kilogramme of water through 1 degree C. is chosen as the unit for measuring quantities of heat, and is called a kilogramme-degree. All bodies, with the exception of hydrogen and certain mixtures of alcohol and water, require a smaller quantity of heat than water for raising 1 kilogramme of their substance 1 degree. The number of kilogramme-degrees, or the fraction of a kilogramme-degree required for raising the temperature of 1 kilogramme of a substance through 1 degree is called the *specific heat* of the substance; or, more generally, *the specific heat of a body is the quantity of heat required for raising its temperature through a given range of temperature compared with the quantity of heat which would be required to raise the temperature of the same weight of water to the same extent.*

The specific heat of water is thus = 1; that of hydrogen is = 3·4; that of nearly all other substances is less than unity.

The metal balls are made with the help of a bullet-mould, into which the iron wire is placed before the molten metal is poured in. The end of the wire is previously bent into a small loop which fixes it in the ball; its projecting portion should be about 10^{cm} long. The small projecting quantity of metal which fills the opening of the mould should be left, as the wire might be cut in attempting to remove it; but any other adhering portions produced by the overflowing of the metal when it is poured in should be cut away with a knife or the pincers. For heating the bullets a pot nearly full of boiling water is used, small enough to allow the wires to project sufficiently for seizing them conveniently with the fingers. The adhering drops of water should be thrown off by a suitable quick motion of the hand, before placing the bullets upon the cake. This should be done quickly, and, to prevent their gliding or rolling

off, the wire handles should be loosely held by the fingers. The two bullets must not be placed near to each other, but several centimetres apart.

If the bullets are made in the small mould used for previous experiments, the cake should be of tallow, which is melted and allowed to become cold in a small shallow round vessel, such as the lid of one of the tin cases in which some kinds of groceries are sold. If the student is able to procure a larger mould, the bullets will contain more heat although the temperature is the same, and a thin disc of beeswax should be used for the experiment. A saucer is half filled with water, and 30 grammes of white beeswax is put into it. The whole is placed in a kitchen oven until the wax is melted, then taken out and allowed to cool slowly without disturbing it. As soon as the wax has become solid, the sharp point of a knife should be led all round between the cake and the saucer, so as to loosen the cake; otherwise, as the contraction goes on, the wax will show fissures, and may even be broken up into several pieces. The cake should not be lifted from the water for some hours more, so that it may become thoroughly hard. The cake should, if possible, be supported during the experiment on one of the rings of the stand previously described.

The zinc bullet produced by the small mould melts about half into the cake; the lead bullet only very slightly. If larger bullets are used, the lead will still sink only very little into the cake, while the zinc melts its way right through it.

Iron has a greater specific heat than zinc, while that of bismuth is still less than that of lead. A bullet of iron may be prepared with some little trouble, with the help of the file, from a piece of round bar iron, and a hole may be drilled through it for the wire handle. The bullet of bismuth may be made in the mould. The iron melts deeper into the wax, or more quickly through it, than the zinc; the bismuth melts scarcely at all into it.

The accurate measurement of the quantities of heat received or given out by a definite body while its temperature is respectively raised or lowered from one temperature to another—in other words, the determination of the specific heat of a body—is a very laborious and difficult experiment, and complicated calculations are required in order to obtain very exact results. The reason of this is that there exist no means of pre-

venting transmission of heat in all directions during the experiment. By surrounding a body with bad conductors it is possible to retard the mutual transmission of heat between the body under experiment and surrounding bodies; but it is absolutely impossible to prevent gain or loss of some heat during the experiment, and the difficulty of ascertaining and allowing for the quantity thus lost or gained, makes the accurate measurement of specific heats, and many similar operations, very complicated and troublesome. The following few determinations of specific heats are therefore only intended as general illustrations, not as examples of experiments by which these specific heats could actually be determined in an exact manner, since the necessary corrections are completely neglected.

500 grammes of water is poured into a large flask of thin glass, and a thermometer is suspended in the water. In another flask the same weight of water, viz. 500 grammes, is heated, and its temperature is also ascertained by a thermometer. When the water in the second flask nearly boils, it is quickly poured into the flask containing the cold water, both thermometers having been read off just previously. The mixture is briskly stirred with a splinter of wood, and the temperature observed. The temperature of the mixture will be the arithmetical mean of the two temperatures previously observed, viz. that of the cold and of the hot water. If, for example, the temperature of the cold water was 15° , that of the hot water 95° , the temperature of the mixture will be found to be

$$\frac{15 + 95}{2} = 55^{\circ}, \text{ or somewhat less, because a portion of}$$

the heat of the hot water is applied to heating the glass vessel and the surrounding air. But if we neglect this loss we may say that 500 grammes, or 0.5 kilogramme of hot water, in cooling from 95° to 55° , parts with $0.5 \times 40 = 20$ thermal units or kilogramme-degrees, and these 20 kilogramme-degrees are just sufficient to raise the temperature of $0^{\text{kg} \cdot 5}$ through $\frac{20}{0.5} = 40^{\circ}$, that is, from 15° to 55° .

But if equal weights of different substances, each at a different temperature, be mixed, the temperature of the mixture will no longer be the mean of the two temperatures. Into a somewhat large flask $1^{\text{kg} \cdot 1}$ of water is poured, and $1^{\text{kg} \cdot 1}$ of mercury is heated in a small flask until the temperature of the mercury is as nearly as possible 74° higher than that of the water; for example, if the water is at 15° , let the mercury be heated to 89° . As soon as the mercury has the desired temperature, it is poured in a thin stream into the water, briskly stirring the mixture at the same time. The water and the mercury will soon have the same temperature, which will be found to be only 2° higher than that of the water before adding the mercury. If the water was at 15° , and the mercury at 89° , the temperature of the mixture will be 17° . One kilogramme of mercury, therefore, in cooling from 89° to 17° , that is, through 72° , has only parted with as much heat as is required to raise the temperature of 1 kilogramme of water through 2° , or 2 thermal units. Now, if one kilogramme of mercury, in cooling through 72° , parts with 2 thermal units, it will part with only $\frac{2}{72} = \frac{1}{36}$ th of a thermal unit in

cooling through 1° ; and conversely, 1^{kg} of mercury will take up $\frac{1}{36}$ th of a thermal unit if its temperature is raised through 1° . Hence the specific heat of mercury, as given by this experiment, is $\frac{1}{36}$ or 0.028.

The little flask containing the mercury should, for the sake of safety, be heated in a 'sand bath.' It is placed upon a layer of dry sand, or still better of dry iron filings, about 1^{cm} high, contained in an iron or tin saucer, which is supported over the spirit or gas flame.

With a wide centre-bit a hole is bored in a pretty large block of ice, which must be as compact and free from bubbles as can be obtained. The hole should be just deep and wide enough to receive one of the leaden weights of 98^{gr} , previously used in the experiments on the laws of motion (see pages 48 and 55, and fig. 56). A thin thread is tied to the weight, by means of which it is held for some time immersed in boiling water; the weight is then quickly taken out of the water and placed in the hole in the ice, which, just previous to putting the lead into it, must be carefully wiped smooth inside with a rag, so as to remove any small loose bits of ice left in the hole; water which may have collected in the hole should be sucked up with a pipette or a suitably prepared pointed tube. After the lead has been left for a few minutes in the ice, and has given up its heat to it, it is taken out again, and the water now left in the hole is carefully sucked up with a pipette and dropped into the smaller graduated tube, fig. 39, page 38. Its bulk will be about $3^{\text{cc}}.75$. The hole in the ice is now enlarged by scraping with a knife until it is about 6^{cm} wide and deep, and, after carefully

removing loose bits of ice and the collected water, 98^{gr} of water, which has been heated until it nearly boils, is poured into the hole, and stirred with the thermometer, until the temperature has fallen to 0°. The water is then removed by a pipette, and its volume will be found to be about 220^{cc}·5, so that the original quantity poured in has increased by 220·5 — 98 = 122^{cc}·5. These quantities can of course only be given approximately, on account of the sources of error mentioned previously.

The result of the experiment would thus be that 98^{gr} of lead, in cooling from 100° to 0°, have given up a quantity of heat sufficient to melt 3^{gr}·75 of ice, while the same weight of water, when cooled through the same range of temperature, gave up heat sufficient to melt 122^{gr}·5 of ice. The quantities of heat given up by the water and lead when cooled through the same number of degrees are thus in the proportion of 122·5 : 3·75, and the same quantities of heat would be required to raise water and lead respectively from 0° to 100°; hence, since the specific heat of water is = 1, we have the proportion

$$122.5 : 3.75 \quad 1 : x$$

$$x = \text{specific heat of lead} = 0.03.$$

It has been already mentioned in connection with the determination of the fixed points of the thermometer scale, that during the melting of ice, and during the boiling of water, the temperature remains stationary, although quantities of heat are continually being taken up both by ice while it is converted into water and by water when it is converted into steam. The heat taken up by ice at 0° while it is becoming water at 0° is expended in melting the ice; the heat applied to boil-

ing water at 100° while the water is becoming steam at 100° is in the same way expended in the evaporation of the water. This heat disappears without producing any rise of temperature, and hence is called *latent* heat. The heat which has become latent may, however, be reproduced, or given out so as to become sensible, when the liquid solidifies, or steam is reconverted into water. If water is to be converted into ice, it is not sufficient merely to cool it to 0° . Water in a vessel, which is placed in a larger one containing ice at 0° , does not freeze; it is necessary to bring the water in contact with bodies which have a temperature lower than 0° , so that, after the water has fallen to 0° , still more heat may be withdrawn from it; in other words, water at 0° must give out heat in order to be converted into ice, and the quantity of the heat thus to be given out is precisely equal to the quantity which disappears when ice at 0° is converted into water at 0° . A liquid, while solidifying and reproducing the heat which has become latent, does not alter its temperature. A corresponding reproduction of heat, without change of temperature, takes place when a vapour passes into the state of a liquid.

The reproduction of heat which has been expended in altering the state of aggregation of a body can be most easily observed in the case of liquids whose point of solidification has been retarded. Thus, if melted hyposulphite of soda is caused to solidify by adding a small grain of the solid substance, the heat given out at the moment of solidification is sufficient to be felt by hand.

If 1^{kgr} of ice at 0° is placed in 1^{kgr} of water at 80° , the ice melts and 2^{kgr} of water at 0° are obtained. The whole of the heat given up by the water at 80° cooling

down to 0° is expended in melting the ice, and we may say that in melting 1 kilogramme of ice 80 thermal units have become latent, or more briefly that the latent heat of water is 80.

The determination of the latent heat of water cannot well be actually made in the simple manner just mentioned, because the last portion of the ice melts so slowly, in consequence of the temperature being not very much above 0° when the greater portion is already melted, that a considerable quantity of heat is taken up from the surrounding air by the vessel containing the liquid and the ice. The experiment may be made in the following manner. In a cylindrical vessel of thin glass with a very thin bottom—a so-called ‘beaker’—500^{gr} of water is heated to 60° in a sand bath, or over a layer of iron filings spread on a disc of sheet metal. When the water is at 60° , 200^{gr} of ice is thrown into it, the mixture stirred, and when all the ice is just melted, the temperature is observed. It will be about 20° . In this experiment 500^{gr} or 0^{kg}·5 of water has had its temperature lowered from 60° to 20° , and the heat given up by the water is therefore $40 \times 0\cdot5 = 20$ thermal units. These 20 units have melted 200^{gr} of ice and converted it into water at 20° . Now 200^{gr} or 0^{kg}·2 requires $20 \times 0\cdot2 = 4$ thermal units to raise its temperature from 0° to 20° ; hence of the 20 thermal units given up by the water only $20 - 4 = 16$ have been expended in melting the 200^{gr} of ice. If 0^{kg}·2 of ice requires 16 thermal units, the quantity required by 1^{kg} will be found from the proportion

$$0\cdot2 : 1 :: 16 : x$$

$$x = 80 \text{ thermal units;}$$

that is, the latent heat of water is 80.

While the latent heat of water may be actually found by observing how much heat a quantity of ice withdraws from a quantity of water during the passage from the solid into the liquid state, the latent heat of vapour is better determined by observing how much heat is given up by a certain quantity of vapour in passing from the gaseous into the liquid state.

A retort nearly filled with water is provided with a glass tube bent at right angles, and clamped in a retort-

stand, so that the end of the glass tube is directed downwards. The water is heated, and as soon as a strong jet of steam issues from the tube a beaker containing 360 grammes of water, heated (or in the summer cooled) to about 20° , is placed under the end of the glass tube as shown in fig. 399, so that the end dips in the water. The water is now constantly stirred with a thermometer, and the steam allowed to enter the water until the temperature has risen to 40° . The

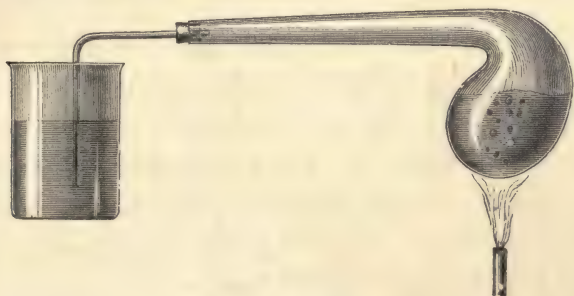


FIG. 399 ($\frac{1}{8}$ real size).

beaker is then quickly withdrawn and weighed. The weight of the water will be found to have increased by about 12 grammes ; that is, 12 grammes of vapour have been condensed into water. In this experiment 360^{gr} of water, that is, 0^{kg}·36, which were originally in the beaker, have been raised from 20° to 40° , and have therefore taken up $0.36 \times 20 = 7.2$ thermal units. The whole of these 7.2 thermal units have, however, not been supplied by the latent heat of the 12^{gr} of vapour ; for these 12^{gr} or 0^{kg}·012 of vapour have, after being condensed to water of 100° , been further cooled from 100° to 40° , and have given up $0.012 + 60 = 0.72$ thermal units which have been expended in heating the water originally in the beaker. It follows that of the 7.2

units received by this water only $7.2 - 0.72 = 6.48$ units have been actually supplied by the 12^{gr} of vapour in its passage to the liquid state ; that is, $0^{\text{kg}} \cdot 012$ of vapour at 100° gives up 6.48 units of heat in becoming $0^{\text{kg}} \cdot 012$ of water at 100° . The heat given up by 1 kilogramme of vapour under the same circumstances follows from the proportion

$$0.012 : 1 :: 6.48 : x$$

$$x = 540.$$

That is, 1 kilogramme of vapour at 100° gives out 540 thermal units in becoming 1 kilogramme of water at 100° ; conversely, 540 thermal units become latent if 1 kilogramme of water at 100° is converted into steam.

59. *Means of raising and lowering the temperature of bodies.*—The heat which becomes latent when solids become liquids, and liquids become vapours, and that which is given out by vapours and liquids when they return to their original state, is very often not only a cause of considerable alterations of temperature, but also a means of artificially producing such alterations. The temperature of bodies may be artificially *raised* by various means; but for *lowering* the temperature of a body the disappearance of heat during changes of the state of aggregation presents, in almost all cases, the most ready means.

The most common means of producing heat is combustion, which however is a chemical phenomenon, and the discussion of it, as well as of many other chemical processes in which heat is produced—such for example as the slaking of lime—belongs to the science of Chemistry and not to Physics.

The *friction* of two bodies one against the other is an important source of heat. Although this source is not ordinarily used for producing large quantities of heat, such as are obtained by combustion, still advantage is taken of it for producing heat on a small scale on exceedingly numerous occasions for lighting fires. The most ancient method of lighting a fire was by pressing the end of an elongated piece of wood between two other pieces and making it rapidly revolve by means of a bow and string of catgut, in the manner in which the drill-bow is used. In the case of flint and steel, the friction of the flint against the steel raises the temperature of the metallic particles, which fly off heated to such an extent that they ignite the easily inflammable tinder or fusee upon which they fall. In the more modern matches friction is used for producing sufficient heat to make the very inflammable matter with which the match is tipped catch fire.

Pressure and *percussion* produce heat. A piece of lead, a few centimetres long and broad, and 1 or 2^{cm} thick, becomes sensibly heated if it is placed upon a hard support, such as a flat stone or an anvil, and is steadily and vigorously hammered for some time.

This is only a special case of the more general and highly important principle, that heat appears whenever mechanical work is done without producing an equal amount of mechanical work in some other form. Experiments prove that for every 424 kilogramme-metres of work which disappear there appears one kilogramme-degree of heat. Conversely, when mechanical work is produced by heat, as in a steam

engine, heat disappears, and for every thermal unit which disappears 424 kilogramme-metres of work is produced. Hence 424 kilogramme-metres is the *mechanical equivalent* of 1 kilogramme-degree of heat.

The production of heat by the compression of gases may be shown by means of the so-called pneumatic syringe, fig. 400. It consists of a glass tube with thick sides, closed at the bottom, and furnished with a leather piston which fits air-tight and is attached to an iron piston rod with a wooden knob. At the bottom of the piston there is a hollow piece of brass in which a piece of tinder may be fixed to a small horizontally projecting brass pin. The tube being full of air, the piston is suddenly pushed downwards as forcibly and rapidly as possible. The air thus compressed disengages so much heat as to ignite the tinder, which is seen to burn when the piston is rapidly withdrawn.



FIG. 400
($\frac{1}{3}$ real size).

The rapid withdrawal of the piston is necessary, for the small quantity of air in the cylinder is insufficient to maintain the combustion of the tinder for more than an exceedingly short time.

It is not always possible to withdraw the tinder burning. Sometimes only a flash is seen just when the piston is pushed down to the lowest point. Before the experiment is repeated, whether the preceding one was successful or not, a narrow tube reaching down to the bottom must be introduced into the syringe, and the air must be sucked out, so that the apparatus may be filled with fresh air for each experiment.

The piston must be well greased with oil, so as to close air-tight and yet to move smoothly.

A piece of the yellow tinder sold by tobacconists should be used.

This consists of thick parallel threads which are interwoven with thinner threads. A very short piece of a thick thread should be pulled off the end of a piece and used for the experiment.

The production of sensible heat during the solidification of liquids—as, for example, in the former experiment with hyposulphite of soda of which the point of solidification had been retarded—has not yet found any practical applications. The heat produced during condensation of steam may however be advantageously used for heating substances which cannot be exposed to an open flame. In a vessel of wood or of thick glass which cannot be directly heated over a flame, because the one would burn and the other crack, cold water may be made to boil by passing a jet of steam into the water through a tube. The great advantage of this mode of heating by steam is that the temperature produced cannot exceed definite limits; for example, in heating the water hammer, fig. 396, by steam—since it is impossible that the apparatus can be heated beyond 100° , the pressure in the interior can never exceed that of the atmosphere, and therefore we need not fear that the apparatus will be broken.

When a solid body is liquefied, a certain quantity of heat must be supplied to it; this heat disappears, or becomes latent, and the temperature of the body remains the same. But if a body is liquefied without receiving a supply of heat from without, then, since heat is under any circumstances necessary for producing the liquefaction, a diminution of temperature must take place. It has been previously stated (see page 213) that a number of solid bodies dissolve in certain definite liquids because the adhesion between the solid

and the liquid is greater than the cohesion between the molecules of the solid. If a body dissolves, it passes from the solid into the liquid state, and liquefaction by solution is accompanied by a disappearance of heat, just as if the body had been heated in order to liquefy it. Every solution of a body, therefore, produces a lowering of temperature. In those cases, where an apparent exception to this law is observed—as, for example, in the solution of caustic potash (see page 679) in which a considerable quantity of heat is disengaged—the solution is accompanied by chemical combination which produces in this and other similar cases much more heat than that which becomes latent by the liquefaction.

Nitrate of ammonia is a very soluble salt, and its solution produces a considerable lowering of temperature. If it is dissolved in about an equal weight of water, and the mixture is briskly stirred, its temperature falls from the ordinary temperature of the air to about -14° .

A mixture of equal weights of nitrate of potash and sal-ammoniac lowers the temperature, not so much as nitrate of ammonia, but still produces a considerable diminution of temperature. If 100^{gr} of powdered nitrate of potash (saltpetre) and 100^{gr} of powdered sal-ammoniac are dissolved in 200^{cc} of fresh water in a large tumbler, and the mixture briskly stirred for about ten minutes with a long thin test-tube which has been half filled with water, a considerable portion of the water in the test tube will be found to be frozen.

If it is only intended to show the lowering of the temperature by the thermometer, without formation of ice, the quantities used may be 25^{gr} of each salt and 50^{cc} of water, which are stirred in a small glass with the thermometer.

If the salt, instead of being dissolved in water, be mixed with ice, the diminution of temperature is still more considerable, because not only the salt but the ice also becomes liquefied, and more heat disappears.

Such mixtures, one of which, consisting of ice and common salt, has been used in a previous experiment, are usually called 'freezing mixtures.' The fall in temperature is the greater the more intimate the mixture is ; for in that case the liquefaction and hence the disappearance of heat take place more rapidly. The ice should therefore be pounded to as small pieces as possible (snow is better than ice), and the mixture constantly and very briskly stirred. If a mixture of about 900^{gr} of finely pounded ice and 300^{gr} of salt be well stirred, the temperature soon falls to -21° , and remains at this point for some time. If some of the mixture be placed in a tumbler, the outside becomes coated with a layer of ice, like that which forms on window panes on a cold day in the winter ; the cold glass condenses upon its sides the vapour of water contained in the air near it, and the water formed by the condensation becomes frozen.

Considerable quantities of heat become latent during the evaporation of liquids, and if the quantity which disappears in evaporating a liquid is not constantly replaced from any source of heat, evaporation becomes, like liquefaction, a means of lowering temperature.

It is from this cause that moist bodies are apt to produce a sensation of cold ; they are constantly evaporating, and hence their temperature falls below that of surrounding bodies. Liquids, whose boiling points are below that of water (ether, alcohol, disulphide of carbon) and therefore evaporate more rapidly, are capable of producing considerable diminution of temperature. If the evaporation of ether be accelerated by passing a rapid current of air through the liquid so as

to remove the vapour as fast as it is formed, the evaporation proceeds at a much increased rate, and the temperature of the liquid may fall to -15° .

A pair of bellows are best for the experiment. If none are at hand, the current of air may be blown by the mouth through the liquid, provided the warm air is first passed through cold water. Fig. 401 shows a suitable arrangement for this purpose. A capacious bottle is about half filled with water and closed by a cork, twice perforated for the reception of two glass tubes, which have a width of about 5 or 6^{mm}. One of the tubes which dips into the water



FIG. 401 ($\frac{1}{4}$ real size).

and goes nearly to the bottom of the flask has a piece of india-rubber tubing attached to the end through which the air is blown in by the mouth. The other tube is bent twice at right angles; one end passes just through the cork, and the other dips into a large test-tube which may be clamped in the retort-stand and is one third filled with ether. When air is strongly blown through the apparatus the test tube becomes covered with a coating of ice, and a thermometer dipped in the liquid falls to -15° .

The india-rubber tube should be pretty long, so that the experimenter need not be too near the test tube containing the ether. The great quantity of ether vapour produced is apt to cause headache. On account of the inflammability of the vapour, the experiment should not be performed by gas or candle light. The india-rubber

tube should not be too narrow, but should allow a large quantity of air to be blown through it without too much exertion.

If the student has set up a reservoir, like that represented in fig. 176, and described on page 255, and has a very large bottle of about 10 litres capacity, the current of air may be produced in a different and more convenient manner. The empty bottle is closed by a cork, through which two tubes pass, as in fig. 401. The tube on the left, which need not reach so far in the bottle in this case, is connected with the reservoir; water is allowed to enter the empty bottle, and as it flows in, the air is forced out and passes in a strong current through the ether.

In a vacuum ether evaporates at an exceedingly rapid rate, and produces thereby a considerable diminution of temperature. A small wooden block is placed upon the plate of the air-pump, a little water is dropped on it, and a watch-glass is placed upon the water. Ether is poured into the watch-glass until it is quite full, and the whole arrangement, which is shown in fig. 402, is then covered by the glass receiver. When the air is exhausted, a considerable portion of the ether evaporates very rapidly, and after a few minutes the water between the watch-glass and the wood becomes frozen. Air is then let in, the receiver is lifted up, and the result of the experiment may be readily inspected.

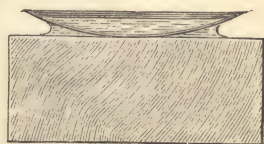


FIG. 402 ($\frac{2}{3}$ real size).

It is advantageous to use a small and rather shallow receiver for this experiment. A small glass cover, such as is frequently used for domestic purposes, will serve very well, if its edge is previously ground with emery powder upon a flat iron-plate, and afterwards, if possible, upon a piece of plate glass, until it is quite smooth and flat all round.

If a nearly perfect vacuum can be produced, even water may be frozen in consequence of the diminution

of temperature caused by its own rapid evaporation. A shallow vessel half filled with concentrated sulphuric acid is placed under the receiver of the air-pump. In the acid a very small vessel cut out of a piece of cork, and covered inside with lampblack, is supported by three legs of glass. About 1 or 2^{cc} of water is poured into the cork vessel, and the receiver is exhausted as perfectly as possible. Fig. 403 gives a section of the

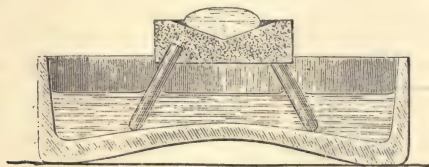


FIG. 403 ($\frac{1}{2}$ real size).

apparatus containing the liquids. As soon as the air is removed, a rapid evaporation of the water commences, and the receiver would soon be filled with vapour of water, which would have again to be pumped out, in order that the evaporation might continue, were it not for the sulphuric acid, which has the property of eagerly absorbing aqueous vapour. The vapour of water, after the air is removed, is absorbed by the sulphuric acid as rapidly as it is formed. After some time the temperature of the water falls to 0° , and it begins to freeze. Frequently the solidification is retarded; the temperature sinks below 0° , and the whole mass freezes all at once.

The air-pump used for this experiment must be a good one and in working order, while the preceding experiment will succeed even if the exhaustion is not very perfect. The tension of aqueous vapour at 0° is 4^{mm}.6 (see page 799); it follows that the pressure of the air under the receiver must be reduced to at least 4^{mm}.6 if the evaporation is to continue after the temperature has fallen to

0°. The density and pressure of the rarefied air must thus amount to considerably less than $\frac{4.6}{760} = \frac{1}{166}$ of its original density and pressure.

The shallow basin for the sulphuric acid is cracked off with pastille from a bottle, of which the upper portion may be broken. The little cork vessel is cut with a knife. The three legs are formed of small pieces of glass tubing, of which the lower ends are closed by the blowpipe, otherwise the sulphuric acid rises in them by capillary attraction and destroys the cork vessel. The blackening of the inner side of the cork vessel (over a burning strip of wood dipped in turpentine or paraffine oil) has the advantage that very little heat can be transmitted by the cork to the water, because lampblack is not moistened by water, and there is hence only very slight contact between the water and the vessel in which it is contained.

The evaporation of the water proceeds sometimes without the production of bubbles. Sometimes it boils briskly, and in some instances the surprising phenomenon may be observed that a layer of ice is lifted by boiling water at 0°.

Ice itself evaporates in a vacuum, and when the pump and receiver hold a vacuum well, the ice formed may be seen to diminish and disappear altogether in a few hours without previously melting.

Water may be frozen by its evaporation without the help of the air pump, by means of a contrivance called the *cryophorus*. It consists of a bent glass tube provided with a bulb at each end. The apparatus is prepared by introducing a small quantity of water, which is then boiled until all air is expelled by the steam. It is then hermetically sealed, so that on cooling it contains nothing but water and the vapour of water. If now the water is allowed to collect in one bulb while the other is immersed in a freezing mixture, the vapour in the tube is condensed, and as the water in the other bulb commences to yield rapidly more vapour, this rapid evaporation, which requires a large amount of heat, lowers the temperature of the water so considerably that it freezes.

The water-hammer previously used may be employed like a cryophorus. The water is allowed to collect in the bulb, and the apparatus is suspended, as in fig. 404, over the edge of a vessel filled with a mixture of

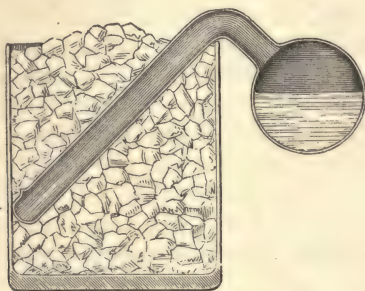


FIG. 404 ($\frac{1}{4}$ real size).

pounded ice and salt. The vapour in the apparatus being condensed, rapid evaporation of the water commences, the temperature sinks gradually to 0° , and the water in the bulb freezes.

In this experiment also the solidification is frequently retarded, and the apparatus must be slightly shaken before the water will freeze. This should be done by gently tapping the sides of the bulb, so that the water may not be too much agitated; for at first only the upper layers sink to 0° , while for some time afterwards the remainder has still a temperature of 4° , and a somewhat stronger agitation might cause the warmer water to mix with the colder, the temperature of which would thus rise again above the freezing point.

The apparatus should be taken out of the freezing mixture when a small quantity of ice appears on the top of the water in the bulb. If the experiment is continued until a compact layer of ice is formed, the apparatus is apt to be broken in consequence of the expansion of the ice.

TABLE I.

SPECIFIC GRAVITY OF SOME IMPORTANT SUBSTANCES.

A. Solids, at 0° C.

Name of Substance.	Weight of one cubic centimetre in grammes.	Name of Substance.	Weight of one cubic centimetre in grammes.
Platinum, coin . . .	22·10	Rock-crystal . . .	2·68
Platinum, laminated . . .	22·07	Porcelain . . .	2·49 to 2·14
Platinum, cast . . .	20·86	Gypsum, crystallised . . .	2·31
Gold, coin . . .	19·32	Sulphur, native . . .	2·03
Gold, cast . . .	19·25	Ivory . . .	1·92
Iridium . . .	18·60	Alabaster . . .	1·87
Tungsten . . .	17·60	Graphite . . .	1·8 to 2·4
Lead, cast . . .	11·35	Anthracite . . .	1·80
Palladium . . .	11·30	Phosphorus . . .	1·77
Silver . . .	10·47	Magnesium . . .	1·74
Bismuth . . .	9·82	Amber . . .	1·08
Copper, hammered . . .	8·88	Wax, white . . .	0·97
„ cast . . .	7·79	Sodium . . .	0·97
„ wire . . .	8·78	Potassium . . .	0·86
Cadmium . . .	8·69	Lithium . . .	0·59
Molybdenum . . .	8·61	Ebony, American . . .	1·33
Brass . . .	8·39	Oak, English old . . .	1·17
Arsenic . . .	8·31	Mahogany, Spanish . . .	1·06
Nickel . . .	8·28	Brazil wood, red . . .	1·03
Steel . . .	7·82	Box, French . . .	1·03
Cobalt . . .	7·81	Oak, English . . .	0·97
Iron, wrought . . .	7·79	Beech . . .	0·85
Iron, cast . . .	7·21	Ash . . .	0·84
Galena . . .	7·76	Apple-tree . . .	0·79
Tin . . .	7·29	Maple . . .	0·75
Zinc . . .	7·00	Riga fir . . .	0·75
Antimony . . .	6·71	Teak . . .	0·74
Tellurium . . .	6·11	Cherry-tree . . .	0·71
Iodine . . .	4·95	Elder . . .	0·69
Heavy spar . . .	4·43	Walnut . . .	0·68
Diamond . . .	3·52	Pear tree . . .	0·66
Flint-glass . . .	3·78 to 3·2	Pitch, pine . . .	0·66
Fluor spar . . .	3·15	Elm . . .	0·60
Aluminium . . .	2·67	Cedar . . .	0·59
Bottle-glass . . .	2·60	Willow . . .	0·58
Plate-glass . . .	2·37	Fir, north of England . . .	0·56
Turmaline, green . . .	3·15	Larch . . .	0·54
Marble . . .	2·84	Poplar . . .	0·38
Emerald . . .	2·77	Cork . . .	0·24

TABLE I.—*continued.**B. Liquids, at 0° C.*

Name of Substance.	Weight of one cubic centimetre in grammes.	Name of Substance.	Weight of one cubic centimetre in grammes.
Mercury	13.596	Wine, Burgundy . .	0.991
Sulphuric acid . . .	1.848	„ Port	0.990
Nitric acid	1.500	Castor oil	0.970
Aqua regia	1.234	Linseed oil	0.940
Hydrochloric acid . .	1.218	Proof spirit	0.930
Blood, human	1.045	Whale oil	0.923
Ale, average	1.035	Moselle wine	0.916
Milk	1.030	Olive oil	0.915
Sea-water	1.028	Ether, hydrochloric .	0.874
Vinegar	1.026	Turpentine, oil of .	0.870
Tar	1.015	Brandy	0.837
Water, distilled, at 4° C.	1.000	Alcohol, absolute . .	0.796
Wine, Champagne . .	0.997	Ether, sulphuric . .	0.720
„ Bordeaux	0.994		

C. Gases, at 0° C. and 760^{mm} pressure.

Oxygen	0.001432	Chlorine	0.003209
Atmospheric air . . .	0.001293	Hydrochloric acid gas .	0.00164
Nitrogen	0.001267	Nitrous oxide	0.00197
Hydrogen	0.0000894	Carbonic acid	0.00198

TABLE II.

COEFFICIENTS OF EXPANSION OF SOME IMPORTANT SUBSTANCES.

A. Solids.—Coefficients of Linear Expansion.

Platinum	0.00000856	Copper	0.00001717
Antimony	0.00000923	Silver	0.00001909
Palladium	0.00001011	Tin	0.00002173
Bismuth	0.00001167	Cadmium	0.00002693
Iron	0.00001225	Lead	0.00002848
Gold	0.00001401	Zinc	0.00002944
<hr/>			
Glass	0.00000861	Marble	0.00000849
Wood (in the direction of the fibres)	0.00000380	Brick	0.00000500

TABLE II.—*continued.**B. Cubical Expansion of Mercury.*

Volume	=	1.000000	at	0°
becomes	,,	1.009013	,,	50°
,,	,,	1.018153	,,	100°
,,	,,	1.027419	,,	150°
,,	,,	1.036811	,,	200°
,,	,,	1.046329	,,	250°
,,	,,	1.055973	,,	300°
,,	,,	1.065743	,,	350°

C. Cubical Expansion of Water.

Temperature	Volume of Water	Temperature	Volume of Water
0°	1.000000	10°	1.000124
1°	0.999947	20°	1.001567
2°	0.999908	30°	1.004064
3°	0.999885	40°	1.007531
4°	0.999875	50°	1.011766
5°	0.999883	60°	1.016590
6°	0.999903	70°	1.022246
7°	0.999938	80°	1.028581
8°	0.999986	90°	1.035397
9°	1.000048	100°	1.042986

1.0

INDEX.

ABS

ABSOLUTE expansion of liquids, 781; rigidity, 152; weight, 33, 34
 Absorbing power for heat, 812
 Absorption of gases by solids, 317; by liquids, 320; of heat, 812; of light rays by vapours, 510
 Acceleration, 62; of gravity, 64
 Accidental colours, 545
 Accommodation of the eye, 517
 Accordion, 388
 Accumulated work, 46, 78; experiments on, 46, 47, 78
 Accumulators of electricity, 618
 Achromatic lenses, 520
 Acoustics, 326
 Adhesion between solids, 154; plates, preparation of, 156; between liquids and solids, 205; compared with cohesion, 207
 Adjustment of eye to varying distance, 517
 Aërostatics and aërodynamics, 219
 Aggregation, states of, 17
 Air, expansive force of, 13; weight of, 219; vibration of, in tubes, 377
 Air-pump, 270; treatment of, 276; rarefaction by, 274; receiver of, 272; experiments with, 280; noxious space of, 275
 Air-tightness of apparatus, how to test, 19
 Alcohol thermometer, 761
 Alloys, 790
 Amalgam for electrical experiments, 552
 Ampère's laws, 693; theory of magnetism, 705
 Ampèrian currents, 701

BAL

Amplitude of vibration, 126
 Analysis, spectrum, 497
 Aneroid barometer, 239
 Angle of incidence and reflection, 429; of refraction, 457
 Angular currents, 694
 Aniline red, divisibility of, 32
 Anisometric parallel projection, 5
 Annealing, 773
 Annular eclipse, 419
 Anode, 673
 Apparatus for making hydrogen, 225, 226
 Aqueous humour, 516
 Aqueous vapour, 793; tension of, 799
 Archimedes' principle, 179, 188
 Area, unit of, 7
 Areas of figures, 3
 Armature, 711
 Arms of levers, 85
 Artificial magnets, 739
 Ascent of liquids in capillary tubes, 209; between surfaces, 211
 Aspirator, how to construct, 264
 Astatic needle, 745
 Astronomical telescope, 525
 Athermancy, 810
 Atmosphere, 13; pressure of, 228; amount of atmospheric pressure, 231; electricity in, 646
 Attraction, capillary, 209; electrical, 553; magnetic, 707
 Attwood's machine, 49
 Axis, optic, 519

BALANCE, 116; conditions to be fulfilled by a good, 117; testing the correctness of, 121

BAL

Balloons, 222
 Bandilore, 103
 Bands of spectrum, 502
 Barker's wheel, 199
 Barium, spectrum of, 503
 Barometer, 232; water, 233; measurement of heights by, 233; how to construct, 234; cistern, 236; siphon, 237; aneroid, 239
 Baroscope, 283
 Battery, galvanic, 653; Bunsen's, 663; Grove's, 660; Daniell's, 684; Meidinger's, 685; treatment of, 664
 Beats, 404
 Beaumé's hydrometer, 196
 Bellows, hydrostatic, 181
 Bells, vibrations of, 371
 Berzelius' lamp, 15
 Binding screws, 656
 Binocular vision, 533
 Blasts produced by centrifugal force, 147
 Bodies, general properties of, 7, &c.; supported in two points, 109; in more than two points, 114; stability of, 115; immersed in a liquid, 187; falling in vacuo, 288
 Boiling, 802
 Boiling point, 765, 802
 Bolognian flasks, 774
 Boomerang-top, 303
 Bramah's press, 162
 Breath-figures, 319
 Broach, use of, 100
 Brush discharge, 601
 Bunsen's battery, 663; burner, 16; photometer, 424
 Buoyancy of liquids, 179

CALCIUM, spectrum of, 494

Camera obscura, 475
 Candle-bombs, 796
 Capillarity, 209; experiments on, 210
 Carbon-disulphide prism, 481
 Cartesian diver, 266
 Celsius' scale, 762
 Centigrade scale, 762
 Centigramme, 34
 Centimetre, 2
 Centre of gravity, 103, 106
 Centre-punch, 96
 Centrifugal force, 131; experiments on, 136; drying machine, 146; railway, 149
 Charge, electrical, 552, 570
 Chemical action in galvanic batteries, 682

CUR

Chemical effects of electricity, 673
 Chemical harmonicon, 379
 Chimes, electrical, 607
 Chisel, 171
 Chimney, draught in, 785
 Chladni's figures, 368
 Chords, major and minor, 351, 407
 Choroid, 515
 Coatings of Leyden jar, 622
 Coefficients of expansion, 770, 838
 Coercive force, 736
 Coercible gases, 809
 Cohesion, 18, 21; figures, 22
 Coil, primary and secondary, 749; Ruhmkorff's induction, 751; effects produced by, 754
 Collodion, 227
 Colour, 543
 Communicating vessels, 179
 Complementary colours, 544
 Compound pendulum, 128
 Compression of the terrestrial globe, 139
 Concave mirrors, 439; lenses, 478
 Concertina, 388
 Concord, 404
 Condensation upon surfaces, 316; of frictional electricity, 611; of galvanic electricity, 652
 Condensers of electricity, 611
 Condensing pump, 289
 Conduction of electricity, 557; of heat, 813; of sound, 336
 Conductivity of bodies for heat, 813; for electricity, 557
 Conductors of electricity, 559; of heat, 813
 Cone, double, on inclined rails, 112; how to construct, 113
 Consonance, 407
 Consonants, 394
 Constant batteries, 683
 Contact-electricity, 647
 Continuous spectrum, 496
 Convection, 814
 Convex meniscus, 209; mirrors, 450
 Cooling by solution of solids in liquids, 829; by evaporation, 831
 Cork-borers, 9; use of, 10
 Cornet-à-piston, 387
 Cryophorus, 835
 Crystalline lens, 515
 Crystallisation, 215
 Cube for experiments on centre of gravity, 110
 Current of electricity, 655
 Currents, mutual action of, 693; action on magnets, 744; detection of, 746; direct and inverse, 750; Amperian,

CUR

701; magnetisation by, 704; in a heated liquid, 777
 Curvature of liquid surfaces, 209
 Cylinder, volume of, 6

DANIELL'S battery, 684
 Dark lines of the spectrum, 505, 507
 Decigramme, 34
 Decimetre, 2
 Declination, magnetic, 741
 Decomposition, chemical, by current, 673; of white light, 480
 Deflection of a magnet by currents, 744
 Degree of a thermometer, 762; of a circle, 72
 Density, 39; electrical, 587; maximum of water, 778
 Depression of liquids in capillary tubes, 210
 Deviation of light by a prism, 460; angle of, 459
 Diameters of the earth, 139
 Diathermancy, 810
 Die-stock, 93
 Diffusion of liquids, 215; of gases, 321
 Dip, magnetic, 742
 Disc acted on by centrifugal force, 142; Newton's, 541
 Discharge, electrical, heating effects of, 629; luminous effects of, 635; mechanical effects of, 639; magnetic effects of, 643; velocity of, 644
 Discharger, 626; Henley's, 634
 Discord, 404
 Dispersion, 480
 Dissonance, 406
 Distance, adaptation of eye to, 517; of distinct vision, 519
 Distillation, 794; apparatus for, 794
 Distribution of electricity upon conductors, 584; experiments on, 591
 Diver, Cartesian, 266
 Divisibility, 32; experiments on, 32, 33
 Division of circle, 72
 Draught of chimney, 785
 Drills, 27
 Drill-stock, 99
 Duration of electrical spark, 644

FAL

Ear-trumpet, 338
 Ebullition, 792
 Echo, 342; multiple, 344
 Eclipse of the sun, 419; of the moon, 419
 Efflux from orifices, 199; of gases, 301
 Elasticity, 153
 Electrical attraction, 553; repulsion, 555
 Electric batteries, 653; bells, 726; charge, 552, 570; chimes, 607; density, 587; discharge, 600; glow, 601; light, 671; machine, 593; mortar, 642; poles, 654; shock, 626; spark, 635; telegraph, 718; tension, 586; whirl, 605; wind, 604; pendulum, 553
 Electricity, 551; atmospheric, 646; contact, 647; development of, by friction, 551; distribution of, 584; frictional, 551; loss of, 590; mechanical effects of, 639; induction of, 563; velocity of, 644; different kinds of, 556
 Electrodes, 673
 Electrolysis, 673
 Electromagnetism, 700
 Electromagnets, 704
 Electromagnetic machine, 713
 Electrometallurgy, 690
 Electromotive force, 648
 Electrophorus, 575; construction of, 578
 Electroscope, 568; construction of, 572
 Emery-powder, 156
 Emissive power, 812
 Endosmose, 217
 Eolipyle, 797
 Equator, magnetic, 742
 Equilibrium of bodies, 43, 103; neutral, 106; stable, 105; unstable, 105; of floating bodies, 194
 Evaporation, 792; cooling by, 832; latent heat of, 824
 Expansion, 54; apparent and absolute, 781; of liquids, 758; of solids, 757; of gases, 758; linear, 770; superficial, 770; cubical, 770; force of, 771; effects of, 771; during solidification, 791
 Expansive force of air shown, 13
 Experiment, Leidenfrost's, 804
 Extension, 1
 Eye, structure of, 514

EARTH. magnetic poles of, 741; magnetisation by, 743; figure of, 138; compression of, 139

FALLING bodies, motion of, 59; calculation of space traversed by, 61

FIG

Figures, Chladni's, 368 ; cohesion, 22
 Films, liquid, 22, 26
 Filter, self-supplying, 259
 Fire-engine, 296 ; air-vessel of, 296
 Flame-manometer, 395
 Flask, specific gravity, 41
 Flattening of a globe, 140
 Flexural rigidity, 152
 Float, construction of, 775
 Floating bodies, 191 ; in air, 222
 Flow through tubes of unequal bore, 306
 Fluids, 13
 Flute, 382
 Flying top, 303 ; wheel, 304 ; construction of, 305
 Focal length, 444
 Foci of mirrors, 444 ; of lenses, 469
 Focus, 444
 Force, 48 ; coercive, 736 ; electromotive, 648 ; expansive, 13 ; portable, 711 ; centrifugal, 131
 Forceps, 28
 Forces, molecular, 33
 Foucault's pendulum experiment, 130
 Fountains, 197
 Frame saw, 170
 Franklin's pane, 619
 Fraunhofer's lines, 505
 Freezing mixtures, 831
 Freezing point of water, 765
 Friction, a source of heat, 827
 Frictional electricity, 551
 Fulcrum, 83
 Fulminating pane, 619
 Fundamental note, 348
 Fusing points, 787
 Fusion, 787 ; latent heat of, 823

GALILEAN telescope, 527

Galvanic electricity, 647
 Galvanic element, 647 ; current, 655 ; effects of, upon conductors, 668 ; circuit 653
 Galvanometer, 747
 Galvanoplastics, 690
 Gamut, 349
 Gases, 17 ; absorption of, 317 ; expansive force of, 13, 18 ; compressibility of, 13 ; conductivity of, 815 ; diffusion of, 321 ; liquefaction of, 808 ; specific gravity of, 783 ; equilibrium of, 219 ; vibrations of, 375
 Gaseous state, 17
 Gauge for measuring thickness of wires, 95 ; for measuring pressure of air in receiver of air-pump, 277

INS

Geissler's tubes, 638, 754
 Glass tubes, how to cut, 14
 Gold leaf, thickness of, 2
 Governors of steam-engine, 143
 Graduating liquid measures, 37, 38
 Gramme, 34, 779
 Gravity, 7 ; specific, 39 ; determination of specific, 40 ; centre of, 103
 Gravity batteries, 685
 Guinea and feather experiment, 288

HARDNESS, 152 ; scale of, 152

Harmonicon, chemical, 379
 Harmonics, 362
 Heat, 756 ; expansion by, 757 ; mechanical equivalent of, 828 ; radiation of, 810 ; absorption of, 811 ; quantity of, 818 ; unit of, 817 ; specific, 816, 819 ; latent, 823
 Heating by steam, 829
 Height of barometer, 233 ; variations of, 234
 Helix, 700
 Hemispheres, Magdeburg, 279
 Henley's discharger, 634
 Henschel's turbine, 204
 Hero's engine, 797 ; fountain, 247
 Homogeneous bodies, 106
 Humour, aqueous, 516 ; vitreous, 516
 Hydraulic press, 162
 Hydrogen for filling balloons, 224
 Hydrometers, 191
 Hydrostatic bellows, 181
 Hydrostatics and hydrodynamics, 158

ICE, density of, 792 ; fusion of, 791, 824 ; expansive force of, 792

Images, formation of, by lenses, 469 ; by mirrors, 440 ; virtual and real, 440 ; by reflection, 432
 Impenetrability, 7 ; experiment showing, 8
 Incidence, angle of, 429
 Inclination, magnetic, 742
 Inclined plane, 88
 Induced currents, 748 ; high tension of, 753
 Induction, magnetic, 711 ; electrical, 563 ; by currents, 748
 Induction coil, 751
 Inductive action on jets, 581
 Inertia, 43 ; experiments on, 45, 46
 Injector, 797
 Insulation, 561
 Insulating bodies, 559 ; stool, 609
 Insulators, 559

INS

Instruments, optical, 519; reed, 389;
mouth, 389

Intensity of light, 421

Interval in music, 349

Iodine vapour, experiment with, 31

Iris, 515

JAR, Leyden, action of, 625

Jet, electrified, 581

KALEIDOSCOPE, 433

Kathode, 673

Keepers, 711

Key in telegraphy, 723

Key-note, 350

Kilogramme, 34

Kilogramme degree, 817

Kilogramme metre, 73

LATENT heat of water, 824; of
vapour, 825

Laws of motion, experiments on, 49,
50, &c.

Lead, disc of, rotating *in vacuo*, 45

Leidenfrost's experiment, 804

Length, unit of, 2

Lenses, 466; convex, 469; concave,
478; formation of images in, 471

Levels, 159

Lever, 83

Leyden jar, 620

Light, reflection of, 427; velocity of,
410, 413; refraction of, 454; pro-
pagation of, 409; dispersion of, 480;
spectra, experiments on, 487

Lightning-conductors, 646

Lime-light, 507

Linear expansion, coefficients of, 770,
838

Liquefaction of gases, 808

Liquids, buoyancy of, 188; conductivity
of, 814; diffusion of, 204; transmis-
sion of pressure of, 161; properties
of, 10; spheroidal state of, 804;
globular form of, 11; under the
action of centrifugal force, 144; sur-
face of, 158

Lithium, spectrum of, 494

Litre, 7

Lodestone, 739

Long-sightedness, 517

Loss of weight in air, 221

Lowering of temperature by evapora-
tion, 832

Luminiferous ether, 410

MOT

MACHINE, Attwood's, 49

Machines, simple, 79

Magdeburg hemispheres, 279

Magic funnel, 258; disc, 547

Magnetic attraction and repulsion, 707;
declination, 741; dip, 742; equator,
742; induction, 711; needle, 739;
poles, 704, 741

Magnetisation, 737; by the action of
the earth, 743; by currents, 704

Magnetism, 735; the earth's, 740; Am-
pere's theory of, 705

Magneto-electrical apparatus, 751

Magnets, artificial and natural, 739;
action of earth on north and south
poles of, 741; portative force of, 737;
induction by, 736

Magnifying power of microscope, 519

Magnitude, apparent, of an object, 519

Major chord, 351

Manometric flames, 395

Mariotte's law, 240, 243; experiments
on, 243, 244; applications of, 246

Mariotte's bottle, 260

Mass and force, 48; experiments on
action of force upon masses, 51, &c.

Measure of force, 52, 53; of work, 73

Measures for liquids, graduation of, 37,
38

Mechanical equivalent of heat, 828;
effects of electric discharge, 639;
powers, 79

Mechanics, 43

Melting point, 787

Meniscus, 38

Mercury, expansion of, 760, 839; how
to handle, 208; rain of, *in vacuo*, 282

Meridian, geographical and magnetic,
741

Metal, Wood's fusible, 790

Metals, conductivity of, for heat, 814;
for electricity, 559, 656

Metre, 2

Microscope, 519

Mill, Barker's, 199

Milligramme, 34

Minor chord, 351

Mirrors, 427; concave, 439; convex,
450

Mixtures, freezing, 831

Molecular forces, 33; in solids, 151; in
liquids, 204; in gases, 316

Molecules, 33

Monochord, 355; experiments with, 357

Morse's telegraph, 720

Motion, uniform, 60; uniformly accele-
rated, 60; of translation, 43; vibra-
tory, 43; rotatory, 43; experiments

MOU

on, 49, 50, &c.; of falling bodies, 58;
of projectiles, 65
Mouth instruments, 382
Multiplier, 747
Multiple echoes, 344; images formed
by mirrors, 431
Musical intervals, 349; scale, 349;
notes, 348; pitch, 347; quality, 368

NEEDELE, magnetic, 739; dipping,
743; astatic, 745
Negative electricity, 556
Negative pole of a battery, 653
Neutral equilibrium, 106
Newtonian telescope, 532
Newton's disc, 541
Nippers, 28
Nodal points, 360; lines, 368
Nodes, 360
Noise, 344
Non-conductors of electricity, 559
Normal boiling point of water, 767
Notes, in music, 344; pitch of, 347;
quality of, 368; rate of vibration of,
349
Nut of a screw, how to cut, 94

OCTAVE, 348

Oil-globule, form of, suspended in
a liquid, 11
Opaque, 414
Opera-glasses, 527
Optic nerve, 515
Optics, 409
Optical instruments, 514; images, 431;
delusions, 549
Organ-pipes, 382
Oscillations of pendulum, 124
Overtones, 363; of tubes, 384

PAINTS for wooden scale, 236

Pane, Franklin's, 619
Parabola described by projectiles, 69
Parallelogram, area of, 3
Pastille, how to make, 12; cracking of
glass by, 13
Pendulum, laws of, 123; construction
of temporary, 50, 58; Foucault's ex-
periment, 130; electrical, 553
Penumbra, 416
Percussion, heat produced by, 827
Permanent gases, 809; magnets, 736
Persistence of visual impressions, 546
Phenakistoscope, 547

REF

Photometer, Rumford's, 422; Bunsen's,
424
Pigment-colours, 542
Pincheocks, how to make, 20
Pipes, vibration of air in, 377
Pipette, 11
Pitch, 344
Plates, vibrations of, 368
Pliers, round and flat, 20
Pneumatic syringe, 828
Point, boiling, 765, 802; freezing, 764
Points, action of, 588
Poles, magnetic, of the earth, 741; of a
magnet, 704; of an electric battery,
653; mutual action of, 707
Pores, 30
Porosity, 29; of liquids, 30; of gases,
31; experiments on, 30, 31
Positive electricity, 556
Positive pole of a battery, 653
Press, hydraulic, 162
Pressure of liquids, 161; construction
of apparatus for showing, 167; atmo-
spheric, 228; heat produced by, 827;
of air on floating bodies, 269
Primary coil, 749; current, 749
Prince Rupert's drops, 773
Prism, refractive action of, 458; trian-
gular, volume of, 6; construction of,
463
Projectiles, motion of, 65
Proof-plane, 576
Pulley, 87
Pump, air, 270; suction, 291; forcing,
294; condensing, 289; how to con-
struct, 297
Pupil, 515

QUALITY of sound, 368**R**ADIATION, 809

Radiating power, 811
Rarefaction in air-pump, 277
Rays, luminous, 38, 810; heat, 810
Reaction of efflux, 199; of gases, 301
Reaction-wheels, 200
Real image, 440; expansion, 781
Réaumur scale, 762
Receiver of air-pump, 272
Rectangular solid, volume of, 5
Reed instruments, 389
Reflecting power for heat, 811; tele-
scope, 532
Reflection of light, 427; laws of, 429;
verification of laws of, 428; of heat,

REF

811; of sound, 341; double, by glass mirrors, 435; by unsilvered glass, 436
 Reflectors, 532
 Refracting telescope, 525
 Refraction of light, 454; through prisms, 459; through lenses, 466
 Regulator of electric light, 671
 Repulsion, electrical, 555; magnetic, 707
 Reservoir of water for physical experiments, how to construct, 255
 Resonance, 355
 Rest, state of, 43
 Retardation of ebullition, 805; of solidification, 787
 Retina, 515; persistence of impressions on, 546
 Retort-stand, 24
 Reversion of bright lines in spectrum, 507
 Rheoscope, 747
 Rigidity, absolute, 152; flexural, 152
 Rimer, use of, 100
 Ring acted on by centrifugal force, 138
 Rock-salt, heat transmitted through, 811
 Rods, vibrations of, 368
 Rose countersink, use of, 658
 Rotating mirror, 397
 Rotation, motion of, 43; of a disc *in vacuo*, 45
 Rubbers of electrical machine, 592, 595
 Ruhmkorff's coil, 751; effects produced by, 754
 Rumford's photometer, 422

SALT and ice, freezing mixture of, 831
 Salts, solutions of, diminution of temperature by, 829; chemical decomposition of, 673
 Scale of hardness, 152; of a thermometer, 762; for measuring, how to paint, 235
 Scales in music, 349; various, of thermometers, 762
 Sclerotica, 515
 Screw, 90; cutting, 93; clamp, 55; stock, 93; taps, 94; propeller, 201, 303
 Secondary coil, 749; current, 749
 Seconds pendulum, how to construct, 58
 Secular magnetic variations, 741
 Segments, ventral, 360
 Separation of the two electricities, 565
 Shadow, 415
 Shock, electric, 626
 Short-sightedness, 517
 Siphon, 251; Wurtemberg, 254; for objectionable liquids, 254; gauge, 277
 Siren, 345

TEL

Size, estimation of, 519
 Smoke-rings, 339
 Soap-bubble solution, 26
 Sodium, spectrum of, 492
 Solar light, analysis of, 504; spectrum, 504; dark lines of, 505
 Soldering, 27
 Solidification, 786; change of volume on, 791; retardation of, 787
 Solidity, impression of, how produced, 534
 Solids, general properties of, 10; conductivity of, 813; linear and cubical expansion of, 757, 838; molecular constitution of, 151
 Solubility, 214
 Sonometer, 355
 Sound, reflection of, 341; mode of propagation of, 327; velocity of, 333; transmission of, experiments on, 335
 Sounding-box, 336
 Space, measures of, 7
 Spangled tube, 602
 Spark, electric, 635; length of, 598; duration and velocity of, 644
 Speaking-tube, 338
 Specific gravity, 39; table of, 837
 Specific heat, 58; determination of, by fusing ice, 821; by the method of mixtures, 819
 Spectacles, 518
 Spectroscope, 497; construction of, 498
 Spectrum, 400; analysis, 497; of an incandescent gas in Geissler's tubes, 755
 Sphere, volume of, 6
 Spheroidal state, 804
 Spiral, current passing through a, 700
 Spirit-lamps, various kinds of, 15
 Spirit-level, 159
 Stability of bodies, 115
 Stable equilibrium, 105
 Steam-jet pump, 797
 Stereoscope, 533
 Stool, insulating, 609
 Strings, vibration of, 355
 Strontium, spectrum of, 502
 Suction, phenomena of, 301, 309, 797
 Suction-pump, 291
 Sun, analysis of constitution of, 504, 513; eclipse of, 419
 Sympathetic vibrations, 363

TELEGRAPH, electric, 718
 Telescope, astronomical, 525; Galilean, 527; Newtonian, 532; terrestrial, 526

TEM

Temperature, 756; correction for, in barometers, 781; influence of, on specific gravity of gases, 783
 Tempering, 97
 Tension, electrical, 586; maximum, of electrical machine, 599; of aqueous vapour, 799
 Terrestrial magnetism, 740; telescope, 526
 Test-tubes, how to graduate, 38
 Thallium discovered by the spectro-scope, 504
 Thermal unit, 817
 Thermal effects of electricity, 629
 Thermometers, 760; division of scales, 762; determination of fixed points, 765; displacement of zero, 769; alcohol, 761
 Threads of a screw, 90
 Timbre, 355, 368
 Tissue-paper, thickness of, 1
 Tone, 344
 Tonic, 350
 Tools for drilling, 97
 Torricellian vacuum, 238
 Transferring liquids from one vessel into another, 27
 Translucent bodies, 414
 Transmission of heat, 809; of pressure, 161; of sound, 326; of electricity, 559
 Transparency, 413
 Triangle, area of, 3
 Tube, spangled, 602
 Tubes, Geissler's, 638, 754; vibration of air in tubes, 385
 Tuning-fork, 374
 Turbine, 204
 Tweezers, 28

UMBRA, 415

Undulations of light, 410
 Units of length, 7; of area, 7; of volume, 7; of heat, 817; of work, 73
 Unstable equilibrium, 105

VACUUM of an air-pump, 277; formation of vapour in, 833; Torricellian, 238

Valves of pumps, 291
 Vaporisation, 792; latent heat of, 823, 825
 Vapour, aqueous, tension of, 799; formation in closed space, 796; latent heat of, 823; determination of latent heat of, 825; saturated, 807; non-saturated, 808
 Variations of height of barometer, 234; of terrestrial magnetism, 741
 Velocity produced by a definite force,

ZOE

52; of electricity, 644; of sound, 333; of light, 410
 Ventral segment, 360
 Vibration, are of, 126; time of, 345
 Vibrations of rods, 368; of bells, 370; of strings, 355; of air in tubes, 385; of plates, 368; measurement of number of, 345; of notes, 345; of pendulum, 123
 Vice, 56; parallel, 57
 Virtual images, 440; velocities, principle of, 85
 Vision, distance of distinct, 519; binocular, 533
 Visual angle, 519
 Vitreous humour, 516
 Vocal ligaments, 391
 Voice, the human, 390
 Volume, unit of, 7; determination of, 4; of solids, 5, 6; change of, on solidification, 791
 Vowel-sounds, 392

WASHING-BOTTLE, 36

Water, decomposition of, 677; maximum density of, 778
 Water-hammer, 788
 Wave of water, 328; of sound, 330; stationary, 375; progressive, 375
 Wedge, 89
 Weight, 34; absolute, 34; specific, 39; determination of, 40, 190; units of, 34; of air, 220
 Weights, casting and preparing, 35; raised by liquid pressure, 182
 Wheel and axle, 80
 Wheel of life, 547
 Whirl, electrical, 605
 Whirling-table, 132; experiments by means of, 135
 White light, decomposition of, 480
 Wind, electric, 604
 Winds, cause of, 785
 Wine-taster, 256
 Winter's electric machine, 593
 Wire frames, how to construct, for cohesion figures, 28
 Wood's fusible alloy, 790
 Work, mechanical, 46, 72; measure of, 73; experiments on, 74, 75; accumulated, 78
 ZERO of thermometer, 762; displacement of, 769
 Zinc-copper element, 655; battery, 654; -carbon battery, 663; -platinum battery, 660
 Zoetrope, 547

LIST

OF

TOOLS, MATERIALS, AND APPARATUS

REQUIRED FOR THE EXPERIMENTS DESCRIBED IN THIS WORK.

A. TOOLS.

1. Parallel Vice ; Fig. 49.
2. Die-stock, with three pair of dies and 8 assorted taps ; Fig. 67.
3. Steel-hammer.
4. Pincers, for ordinary purposes ; Fig. 33 A.
5. Nippers ; Fig. 33 B.
6. Pliers, flat and round ; Figs. 23, 24.
7. Tail-vice.
8. Files, 1 doz. assorted and adapted to all requirements ; with handles.
9. Rat-tails, two with handles.
10. Rasp, half round, with handle.
11. Mortise-chisels and punches ; set of 6, for various purposes ; Figs. 47, 123.
12. Broaches (Rimers), set of 5, assorted sizes ; Fig. 71.
13. Frame-saw ; Fig. 122.
14. Hand-saws ; two, adapted for physical workshop, with handles.
15. Screw-drivers, two of different size.
16. Gauge for measuring thickness of wire or diameter of holes ; Fig. 68.
17. Chisels, three, of different kinds ; Fig. 47, and 123, A, B.
18. T-square of steel.
19. Shears, for cutting sheet-metal.
20. Rose-countersink ; Fig. 338.
21. Ladle and bullet-mould.
22. Blow-pipe.
23. Drill-bow.
24. Centre-bits with brace, five assorted sizes.
25. Wooden mallet.
26. Fret-saw, with handle.
27. Keyhole-saw.
28. Bradawl, long and round, with handle.
29. Gimlets, six assorted.
30. Hand-vices, two sizes.
31. Hone.
32. Metre-rule, of brass.
33. Forceps, pair of ; Fig. 34.
34. Wire-brush.
35. Crucible-tongs.
36. Large vice.

2 LIST OF TOOLS, MATERIALS, AND APPARATUS.

- | | |
|--|---|
| 37. Drill-stock with breast-plate,
and 8 assorted drills. | 41. Iron Ruler, 50 ^{cm} long, divided
into millimetres. |
| 38. Glue-pot. | 42. Small case of mathematical
instruments. |
| 39. Oil-can. | |
| 40. Grind-stone in frame. | |
-

B. MATERIALS.

- | | |
|--|---|
| 43. Emery-powder, 5 assorted kinds,
100 ^{gr} together. | 49. Brass-wire, 1 ^{kgr} assorted. |
| 44. Jeweller's rouge, 50 ^{gr} . | 50. Sheet-brass, 1 ^{kgr} assorted. |
| 45. Emery-paper, 6 sheets assorted. | 51. Bar steel, 6 bars assorted sizes. |
| 46. Glass-paper. 6 sheets assorted. | 52. Iron, one bar. |
| 47. Lead, 3 ^{kgr} . | 53. Steel bar for centre-punch. |
| 48. Tin, 200 ^{gr} . | 54. Wood-screws, 20 doz. assorted,
12 different sizes. |
-

C. APPARATUS AND CHEMICALS.

SET I.

(Comprising the most indispensable pieces.)

- | | |
|--|--|
| 55. Balance and set of weights, from
0.1 to 500 ^{gr} . | 69. Winter's electrical machine;
Fig. 316. |
| 56. Amalgam, box of, for electrical
experiments. | 70. Goldleaf-Electroscope. |
| 57. Hydrometer, for taking the
specific gravity of liquids. | 71. Machine for Laws of Falling
Bodies, modification of At-
wood's; Fig. 43. |
| 58. Astatic Needle. | 72. Solid Magenta, 10 ^{gr} . |
| 59. Beaker glasses, set of 6, assorted
sizes. | 73. Siphon for dangerous liquids;
Fig. 174, A. |
| 60. Japanned Tin-box, for refraction
experiments; Fig. 257. | 74. Burette. |
| 61. Cartesian Diver. | 75. Glass-tubing, assortment of. |
| 62. Chloride of Barium, 5 ^{gr} , in stop-
pered bottle. | 76. Glass rods, two stout, for elec-
trical experiments. |
| 63. Chloride of Lithium, 1 ^{gr} , in
stoppered bottle. | 77. Glass-flasks and bottles, 1 doz.
assorted sizes. |
| 64. Chloride of Strontium, 5 ^{gr} , in
stoppered bottle. | 78. Glass-retorts, 3 assorted sizes. |
| 65. Brass-sphere for electrical ex-
periments; Fig. 313. | 79. Glass-funnels, 4 assorted sizes. |
| 66. Wire-gauze for heating glass
vessels. | 80. Square glass-vessel, with flat
sides; Fig. 12. |
| 67. Iron wire, 0 ^{mm} .2 thick, a reel of | 81. Pithballs, 1 doz. |
| 68. Bunsen's Elements; Fig. 340. | 82. India-rubber tubing, assortment
of; 3 to 12 ^{mm} wide. |
| | 83. Clamping-screws for apparatus;
Fig. 337, G. |

84. Retort-stands; Fig. 30 and Fig. 383.
85. Water-hammer; Fig. 393.
86. Copper-wire, covered, for electrical experiments; 0^{mm}.6 thick, 50^{gr}; 1^{mm}.5 thick, 100^{gr}.
87. Copper-wire, uncovered, 1^{mm}.5 thick, 100^{gr}.
88. Whirling-Table, Fig. 95; with brass ring, Fig. 99.
89. Spirit-lamp.
90. Bunsen burner.
91. Tinfoil, 4 sheets.
92. Thermometers, 2, graduated on stem.
93. Funnel-tubes, 3.
94. Hyposulphite of soda, 500^{gr}.
95. Small cup of copper for Leydenfrost's experiment.
96. Cadmium, 5^{gr}.
97. Bismuth, 30^{gr}.
98. Leyden Jar.
99. Set of lenses.
100. Magnets, 2.
101. Magnet, swinging on agate cap.
102. Pipette; Fig. 11.
103. Platinum-wire and foil.
104. Two platinum strips with wire, for electrolysis; Fig. 242.
105. Platinum-wire with hook fixed upon glass handles, for spectroscopic experiments.
106. Test tubes, 2 doz.
107. Sulphide of Carbon Prism.
108. Clamp for heating test tubes.
109. Mercury, 1^{kg}.
110. Cork-borers, set of.
111. Ebonite rods for electrical experiments.
112. Graphite, 50^{gr}.

SET II.

113. Spangled tube.
114. Glass plates for experiments on adhesion, 8^{cm} in diameter.
115. Electrical Discharger.
116. Bolognian Flasks, 3.
117. Electrical Condenser.
118. Metal plates for adhesive experiments.
119. Aspirator; Fig. 183, B.
120. Bladder-glass, for showing effect of atmospheric pressure.
121. Prince Rupert's drops, small box of.
122. Baroscope; Fig. 189.
123. Double cone, with rail; Fig. 80.
124. Spirit-level; Fig. 112.
125. Grove's Elements, 2; Fig. 339.
126. Electric Bell; Fig. 366. With push-button.
127. Electro-magnets, two, of different size.
128. Electrophorus.
129. Guinea and Feather apparatus.
130. Receiver for the same.
131. Pneumatic syringe; Fig. 400.
132. Apparatus for manometric gas-flames.
133. Geissler's Tubes, assortment of three.
134. Magdeburg Hemispheres.
135. Hero's Fountain; Fig. 170, B.
136. Eolipyle.
137. Induction-Coil; Fig. 378.
138. Insulating Stool.
139. Disc of lead, with steel axis, for showing effect of resistance of air; Fig. 41.
140. Stereoscope.
141. Air-pump with 2 receivers.
142. Graduated measures, 2, divided in cubic-centimetres.
143. Apparatus for demonstrating Mariotte's law.
144. Monochord.
145. Pinch-cocks.
146. Barker's Mill.
147. Tubulated flask; Fig. 181, A.
148. Violin-bow, for acoustic experiments.
149. Galvanometer.

LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLAMENT STREET

**THIS BOOK IS DUE ON THE LAST DATE
STAMPED BELOW**

AN INITIAL FINE OF 25 CENTS

**WILL BE ASSESSED FOR FAILURE TO RETURN
THIS BOOK ON THE DATE DUE. THE PENALTY
WILL INCREASE TO 50 CENTS ON THE FOURTH
DAY AND TO \$1.00 ON THE SEVENTH DAY
OVERDUE.**

DEC 22 1939

DEC 26 1939

YC 1144

Weinhold
12190
QC21
W4

